6-1-1995

Change Detection of Wetlands in the Sandhills of Nebraska Using Landsat MSS Imagery.

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Change Detection of Wetlands in the Sandhills of Nebraska Using Landsat MSS Imagery

A Thesis

Presented to the Department of Geography/Geology

and the

Faculty of the Graduate College

University of Nebraska

In Partial Fulfillment

of the Requirements for the Degree

Masters of Arts

University of Nebraska at Omaha

by

Rod Fraser

June 1995

THESIS ACCEPTANCE

Acceptance for the faculty of the Graduate College, University of Nebraska, in partial fulfillment of the requirements for the degree Master of Arts, University of Nebraska at Omaha.

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Date July 3, 1995

ABSTRACT

Landsat multispectral scanner (MSS) satellite data was used to identify and analyze temporal change of a wetlands area in the Nebraska Sandhills over an 18 year period. A dual-approach to change detection was utilized: bivariate regression of the spectral data and classification comparison. The former indicates biophysical changes of the land surface, while the latter indicates land cover changes. If both types of changes are found to be significant, then environmental changes of the land surface are revealed. A final analysis involving change images for both the spectral and classification data was conducted to gain insight into the nature of the wetlands and the processes at work. It allowed for the examination of spatial variations of change over time.

Results indicate that the dual-approach to change detection provided unique information on both the spectral variation of the land surface and land cover class changes that neither alone could supply. There was not a statistically significant variation in the land surface between different dates. However, there was still a considerable amount of unexplained variation in the spectral response of the land surface and many areas experienced land cover changes. Seasonal differences were greater than annual changes and changes observed over the course of the study period. Future research studies should differentiate between seasonal and annual change.

ACKNOWLEDGMENTS

I would like to take this opportunity to thank several people whose assistance was invaluable in the completion of this thesis. First, I would like to thank Dr. Jeffrey Peake for his guidance, patience, and time as my thesis advisor. His direction made the completion of this research much easier. I would also like to thank the rest of my committee members: Dr. Michael Peterson for his graphics and literary knowledge, and Dr. Thomas Bragg for serving as an outside committee member and his knowledge of the Sandhills of Nebraska.

I am also grateful for Roger Hubbard's computer assistance. Whether developing computer programs or providing knowledge on data management, his help was invaluable. I would also like to express sincere appreciation to Frank Hartranft of the Campus Computing Center, for his assistance with the SPSS software package, and to Pat Chavez, Jr. of the United Sates Geological Survey, Flagstaff, Arizona, for his personal assistance with atmospheric correction values calculations. Finally, this research was greatly aided by the generous financial support of N.A.S.A., through the Nebraska Space Grant Consortium.

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Chapter I

INTRODUCTION

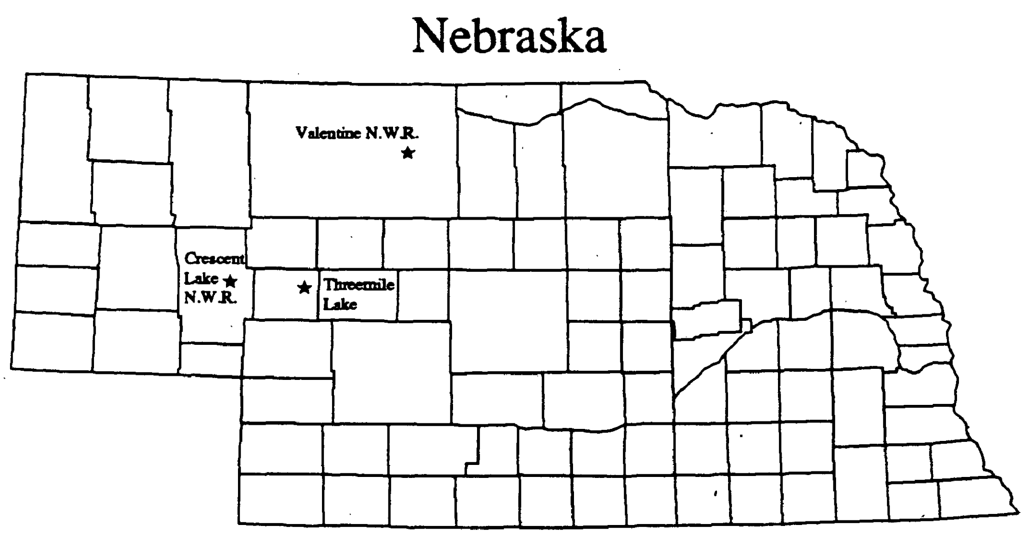
Wetlands are an essential component of the global ecosystem. They function as plant and animal habitat, and they play a role in hydrological and biogeochemical cycles (Walbridge, 1993). In the Sandhills of Nebraska, the habitat functions provide the societal values of recreational hunting and fishing, bird watching, and hay production for ranchers to use as winter cattle feed. The role that the Nebraska Sandhills' wetlands play in the hydrologic cycle has the value of being an important source of water recharge for the Ogallala Aquifer (Dreeszen, 1984). Finally, the biogeochemical role has the values of improving water quality by removing inorganic nutrients and influencing global climate change through carbon storage and methane production (Walbridge, 1993).

With the loss of approximately 53% of these valuable wetlands in the contiguous United States over the last 200 years (Toliver, 1973), the conservation of wetlands is becoming increasingly important. The wetlands in the Sandhills are considered by most authorities to have decreased from the 1930s to the early 1980s, but may again be increasing (Bleed and Flowerday, 1990). Changes in wetland extent and composition occur due to human alterations of the physical landscape, climatic fluctuations, and yearly and seasonal precipitation and evapotranspiration rates. Frequent monitoring of Nebraska

Sandhills' wetlands is being conducted by the University of Nebraska-Lincoln and the University of Nebraska at Omaha at several research sites, including those at the Valentine and the Crescent Lake National Wildlife Refuges and at Threemile Lake (See Figure 1). These research projects monitor the sites and examine seasonal and other short-term processes occurring in these wetlands. However, in order to survey large wetland areas on both seasonal and yearly bases and analyze regional processes, only satellite remote sensing provides a relatively inexpensive and efficient method of collecting data.

Remote sensing has the capability to detect land cover types and monitor land cover changes (Jensen, 1986a), including those occurring in wetlands. For example, by utilizing the infrared portion of the electromagnetic spectrum, a satellite sensor can "reveal changes in vegetative vigor" as well as distinguish between different plant groups (Campbell, 1987). Water surfaces are also highlighted in the infrared, with clear water surfaces having a reflectance near zero. The presence of hydrophytes and/or sediments will change the spectral response, which helps in distinguishing water "contaminants," both spatially and temporally. Remote sensing provides many additional benefits, including repeat coverage for monitoring seasonal or yearly changes, ease of integration of remote sensing data with other sources of data, lower costs per acre than aerial photography and field surveys, and greater spectral sensitivity and wider areal coverage than aerial photography. However, these benefits must be weighed against the major limitation of satellite data: reduced spatial resolution and thus reduced accuracy and detail in identifying certain wetland types and categories in comparison to aerial photographs (Federal Geographic Data Committee, 1992).

Figure 1. University of Nebraska Wetland Study Sites



The Landsat multispectral scanner (MSS) has been proven effective for regional studies. It has relatively good spatial resolution, it is the least expensive imagery for small regional coverage, and it has the added benefit of providing continuous coverage dating back farther than any other earth resource satellite sensor system. This is important for change detection studies that intend to examine long-term fluctuations. Landsat MSS has been used for wetland monitoring at all of the University of Nebraska Sandhills wetland study sites except the one at Threemile Lake.

The purpose of this study is twofold: (1) identify and analyze temporal and spatial change over a 20-year period in the Threemile Lake region wetlands as determined by spectral response fluctuations of Landsat MSS data and (2) establish a data base for future monitoring and analysis of wetlands at the study area. Since many of the processes at work in the Sandhills are long-term in nature, the latter purpose is essential. Three research hypotheses are formulated in this study. The first states that there is statistically significant variation in the spectral response of wetlands over time. This will be tested by a regression of enhanced spectral values for different image dates. The second hypothesis states that there is statistically significant variation among wetland land cover classes over time. This hypothesis will be tested by the Kappa coefficient. The third hypothesis is that statistically significant spectral changes are related to land cover class changes. This hypothesis will be tested by a comparison of spectral changes against classification changes for the study area.

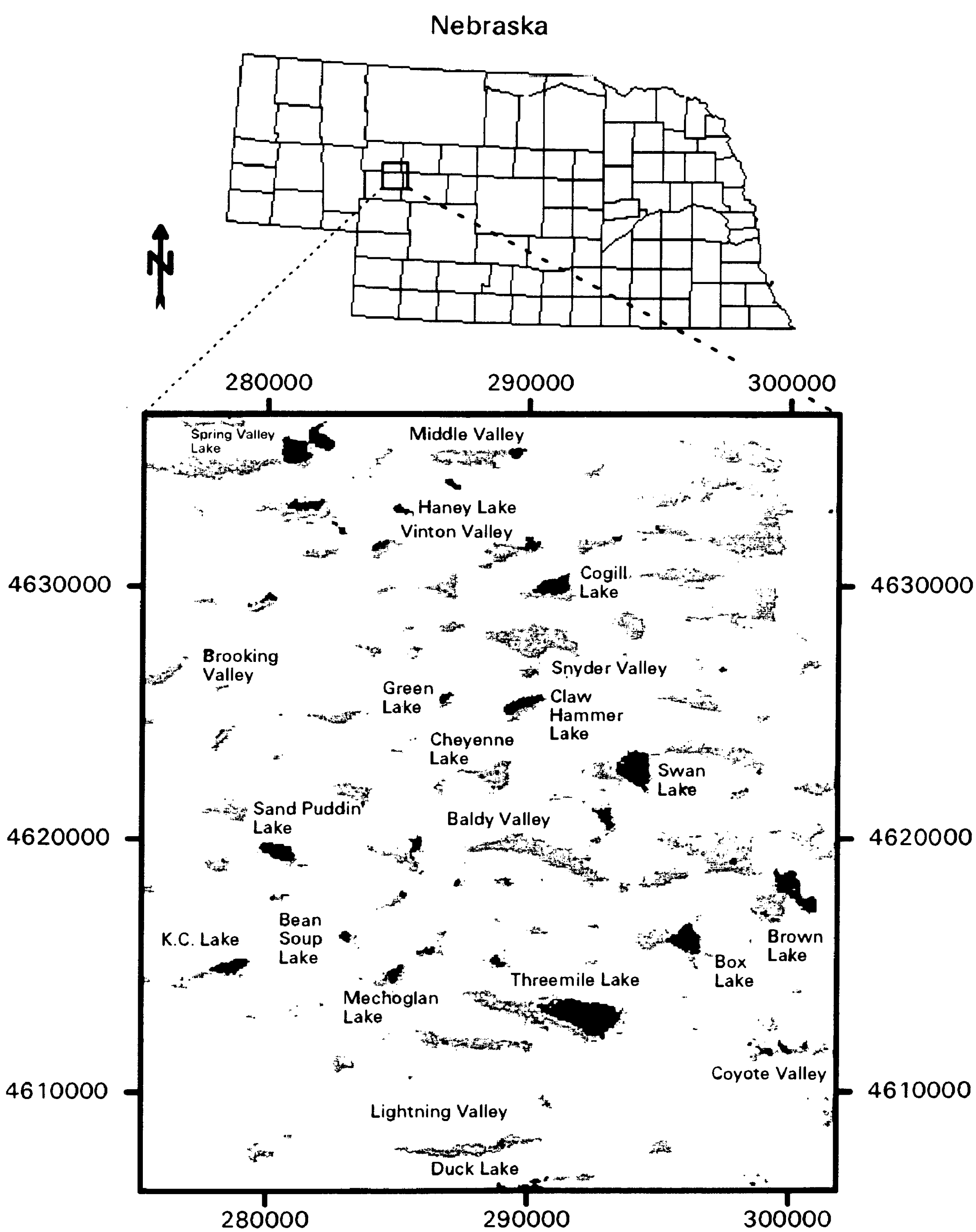
Chapter II

STUDY AREA

The wetlands area used in this study is situated northeast of Arthur, Nebraska (Figure 2). It is located within the southwest part of the Sandhills region and consists of a large group of wetlands surrounded by upland Sandhills. It is an area of approximately 818 square kilometers covering parts of four counties. The climate for this region is transitory between humid continental and dry middle latitude steppe with mean annual precipitation between 43 and 51 centimeters, of which 50% falls from May through July. Summers are warm and winters cold with the growing season extending from April to September (Bleed and Flowerday, 1990).

The landscape was formed by wind-blown sand deposition during the Quaternary period (Smith, 1965). This eolian activity was not of a single event, but of multiple episodes during the last 10,000 years. "Large eolian activity ceased at about 1,500 years ago, but minor periods of drought" have caused local blowouts and the formation of some small dunes (Bleed and Flowerday, 1990). Dunes are commonly 70 to 150 meters in height in the study area, with numerous lakes, marshes, and subirrigated meadows residing in the interdunal valleys. These wetland areas were formed by the infiltration of rainfall

Figure 2. Study Area and Location



Scale

1 : 262036.88

into these highly permeable soils after the last major eolian event. This seepage eventually raised the water table high enough that it intersected the interdunal valleys, creating marshes and lakes (Bleed and Flowerday, 1990).

The sandy soils of this region are of the Entisol order and are made up of the Valentine-Els-Tryon and Valentine soil associations. "These are deep soils on nearly level to very steep surfaces" (Bleed and Flowerday, 1990) which are formed in wind-deposited sands. "Interdune deposits are generally finer grained and more poorly sorted than are the dune deposits. Thickness of interdune sediments in the Sand Hills range from a few meters in surface exposures to 15 m in some core samples" (Ahlbrandt and Fryberger, 1980).

These sandy soils limit surface runoff and allow the percolation of rainfall to recharge the groundwater supply, with the principle reservoir being the Ogallala Aquifer. The Ogallala Aquifer is part of the High Plains Aquifer that extends from central Texas to South Dakota. Its thickest part is in the Nebraska Sandhills, having a maximum saturated thickness of over 152 meters. The depth to groundwater varies with the terrain, being about 91 meters at the top of some dunes and intersecting the surface in some interdunal valleys to form lakes and marshes (Bleed and Flowerday, 1990).

Lakes are affected directly by rainfall, and indirectly though groundwater recharge. They vary in size seasonally and annually depending upon precipitation and evaporation rates. This variation may indicate long-term climatic trends. Lake depths are generally shallow, being less than 1.7 meters (Bleed and Flowerday, 1990).

The wetlands of this region contain numerous plant species, but they can be combined into a few plant communities: meadow, marsh, and aquatic (Bleed and Flowerday, 1990). All of these communities require different levels of soil moisture to maintain seasonal growth and long-term survival. The Wetlands Inventory of Nebraska in 1974 (as cited by Turner and Rundquist, 1980), using Landsat MSS data, defined the following wetland classes that are related to the above plant communities and are applicable to the Sandhills:

> <u>Open Water</u> :
> Areas of open, perennial, surficial water ten acres or larger in size.
>
> <u>Marshes</u> :
> Areas of emergent aquatic vegetation often mixed with small areas of open surficial water. Areas of marsh large enough to be mapped at the working scale of the imagery and adjacent to open surficial water are designated as marsh.
>
> <u>Subirrigated Meadows</u> :
> Areas not irrigated by man that occupy topographic lows where plant roots contact the water table. These topographic lows are usually occupied by vigorously growing grasses, sedges, and shrubs that contrast sharply with adjacent upland vegetation.

Turner and Rundquist (1980) also used Landsat MSS to identify wetland classes for the Wetlands Inventory of the Omaha District (Upper Missouri River basin), U.S. Army Corps of Engineers project, using the following classification:

> <u>Open Water</u>:
> All natural or man-made lakes, ponds, and reservoirs. Rivers and streams and streams with a sufficiently large channel so as to be discernible on the Landsat imagery are also included as fresh open water (or inland saline water in the case of alkali lakes).
>
> <u>Marshes</u>:
> Any potential wetland containing quiescent water holding emergent or floating vegetation; typically grasses, bulrushes (including the hard-stemmed variety), spikerushes, cattails, arrowheads, whitetop, wild rice, reeds, sago, pondweed, and other less-common species. This class includes deep shallow fresh water marshes as well as the inland saline marsh.

Subirrigated Meadows:
Those areas in the Nebraska Sandhills in which the plants derive their moisture directly from the water table instead of from the vadose water. Vegetation in these meadows is made up largely of grasses and sedges with some rushes and other broad-leaf plants. Quiescent water located within a subirrigated meadow is mapped as open water.

These definitions are slightly different from the first study, and this latter categorization will be used in the current study since the maps produced in the Corps of Engineers' project were used as reference data for the classification procedure in Chapter 5.

The study area was selected because of a personal interest in the Sandhills, the availability of satellite imagery for the area, continuing close-range data collection and analysis at Threemile Lake, and the fact that human alteration of the land has been minimal in this region. The latter should help limit detected changes to environmental changes. The Threemile Lake region can thus "serve as an important 'indicator region' for assessing the impact(s) of climate/environmental change" (Rundquist, *et al.*, 1994). It is therefore a good site for monitoring biophysical processes and regional and global climate change.

Chapter III

LITERATURE REVIEW

Relative to other applied remote sensing investigations, wetland studies have been few. Some of the studies used hand-held radiometers (Jensen, 1986b) or very low altitude radiometers (Ernst-Dottavio, 1981) to examine wetland spectral characteristics. Gress *et al.* (1993) and Garcia and Casselles (1990) investigated the use of Landsat Thematic Mapper (TM) data for wetlands inventory review and water quality. Linde and Janisch (1977) used low-altitude color photography and Jensen *et al.* (1984) used airborne multispectral scanner data to map wetlands.

Other wetland studies have used Landsat multispectral scanner (MSS) imagery. Most of these have involved the mapping and delineation of wetlands (Butera, 1983; Raitala *et al.*, 1984; Jensen *et al.*, 1984) and the results have generally been good. Raitala (1986) went beyond mapping in using Landsat MSS for quantitative evaluations and temporal monitoring of wetlands.

Nebraska wetlands have been inventoried dating back to 1955 when the United States Fish and Wildlife Service (U.S. Dept. of Interior, 1955) visually surveyed wetlands located within one-eighth mile of roadways. The Nebraska Games and Parks Commission surveyed wetlands from 1962 to 1968 through the use of aerial photographs (McMurtrey *et al.*, 1972) and found that wetlands had decreased. Color infrared photography was used by the National Wetlands Inventory (NWI), beginning in 1979, to map wetlands using field surveys for verification purposes.

The first satellite remote sensing examination of Nebraska's wetlands was the *Wetlands Inventory of Nebraska, 1974* (Seevers *et al.*, 1975). It used Landsat MSS data to visually classify wetlands. Later studies included the "Lindbergh Study" of 1978 (Rundquist and Linden, 1979), which tested the ability of Landsat MSS to classify wetlands by a simple thresholding procedure. The *Wetlands Inventory of the Omaha District*, U.S. Army Corps of Engineers, which also used Landsat MSS data, inventoried the wetlands in 1978 through a parallelepiped classifier and single- and dual-band level-thresholding (Turner and Rundquist, 1980). Ducks Unlimited used Landsat Thematic Mapper (TM) data to inventory wetlands (Koeln *et al.*, 1986). The accuracy of using Landsat MSS to evaluate wetlands and analyze temporal change was examined by Gilbert *et al.* (1980) and Dinville (1993) for the Valentine National Wildlife Refuge. Despite all of these studies of wetlands in Nebraska, Rundquist (1984) reported that individual surveys could not be directly compared due to differing wetland definitions. Also, classification methods and techniques of data collection were incompatible.

The research conducted by this thesis will expand previous wetland studies, both in Nebraska and elsewhere. It is modeled to some extent on Dinville's (1993) wetland research in the Nebraska Sandhills, but differs in several ways. First, Dinville integrated Landsat MSS and Landsat TM data, while this study uses MSS data only, thereby avoiding problems resulting from spectral and spatial differences in the MSS and TM sensors. This eliminated one more variable from consideration in separating spectral and land cover change from change due to sensor differences. Second, while both studies use a hybrid approach in the classification methodology, encompassing both supervised and unsupervised classification procedures, this study does not alter the original data through such algorithms as buffers and filters as did Dinville's. Third, the accuracy assessment procedure in this study uses more sample points and uses the more reliable Kappa and conditional Kappa statistics which are not biased by the accuracy/agreement of individual land cover categories. Fourth, this study uses a dual-approach to change detection that examines both spectral and land cover classification changes, while Dinville limited his study to a post-classification comparison. This study also involves more spatial analysis of change with both change images and subset statistical analysis. Finally, each study examines a different wetlands area; although, this is beneficial for expanding Nebraska Sandhills wetlands research and for comparing differences in change between areas, thereby helping to understand unique variations within the Sandhills wetlands. Overall, wetland research using remote sensing is advanced in this study, with a new methodology and perhaps insight into the nature and processes of wetlands and how they are being impacted by changes in the physical environment and by man's intervention.

Chapter IV

DATA

Landsat MSS imagery of the study site was obtained for six different dates. These satellite scenes covered an 18-year period and were obtained from several different platforms (Table I). (See Appendix A for additional information on the satellite sensors.)

Table I. Landsat Multispectral Scanner Data

Date	Platform	Temporal Resolution	Altitude
07-26-73	Landsat-1	18 days	900 km
07-01-76	Landsat-2	18 days	900 km
08-01-77	Landsat-2	18 days	900 km
06-12-78	Landsat-3	18 days	900 km
08-11-84	Landsat-5	16 days	705 km
07-14-91	Landsat-5	16 days	705 km

The temporal resolution is 18 days for repeat coverage for Landsat-1 to Landsat-3 and 16 days for Landsat-4 and -5. The spatial resolution is approximately 79m by 79m for all MSS scenes. Landsat-4 and -5 carry both MSS and TM sensors and orbit at a lower altitude to accommodate the higher spatial resolution of the TM data: 30m by 30m. This affects the temporal and spatial resolution of the MSS data on board these platforms. The Landsat MSS consists of six parallel detectors sensitive to four spectral bands relating to the visible and near-infrared portions of the electromagnetic spectrum (Jensen, 1986a), as illustrated in Table II. The bands will be referred to as bands one through four.

Table II. Landsat MSS Spectral Characteristics

Band	Spectral Sensitivity
4 (1)	0.5 - 0.6 μm (green)
5 (2)	0.6 - 0.7 μm (red)
6 (3)	0.7 - 0.8 μm (near-infrared)
7 (4)	0.8 - 1.1 μm (near-infrared)

Bands in parentheses are for Landsat-4 and -5.

Ideally, for yearly change studies, the same date for each year should be compared, but this is usually not possible with Landsat MSS data due to the temporal resolution and the necessity of using scenes that are of high quality: defined as being cloud-free and with very little haze. If different dates are compared, there is the possibility that detected changes may be due to different stages of plant growth and not due to yearly fluctuations of the environment. However, since this study is not dealing with individual species, but is only looking at three general wetland classes, seasonal variation influences are minimized. The change detection methods used should further limit seasonal effects, since changes in spectral characteristics must be large in order to be significant. Furthermore, if there are seasonal effects depicted, they will still be useful in lending insight into the processes occurring in the study area.

In addition to Landsat MSS imagery, a Landsat TM scene of the study area was obtained to aid in image registration and to assist in image classification. Topographic quadrangle maps of the study area were used to aid in image registration and classification. National Wetland Inventory maps from March 1982 and U.S. Army Corps of Engineers wetlands maps from June 12, 1978 were used to assist in delineating wetland features. Aerial photographs from several different years also aided the identification and classification of land cover.

Chapter V

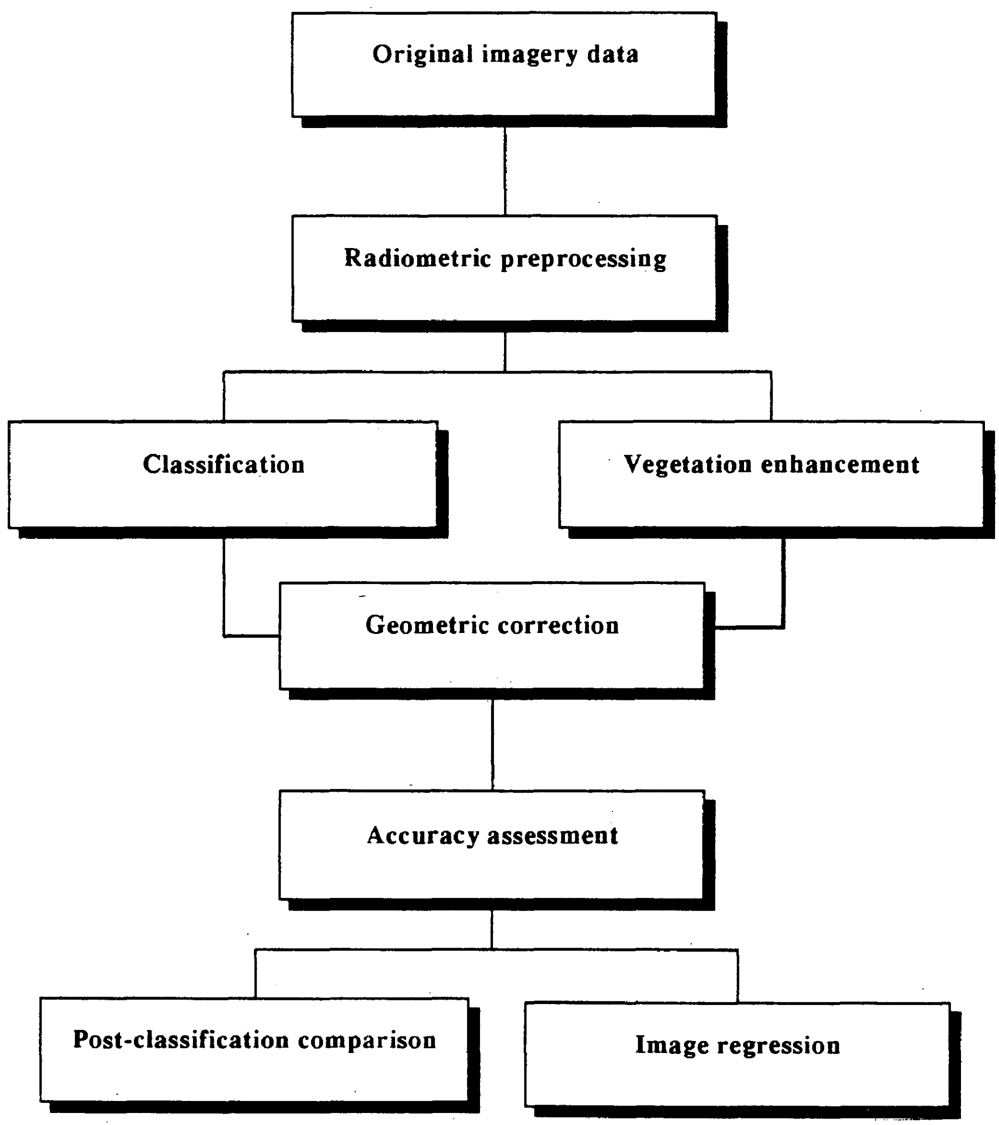
DATA PREPARATION

The raw digital data are in a form that does not allow for accurate quantitative analysis or for the depiction of unique spectral characteristics of the land surface. There are errors inherent in the sensor itself and in its representation of the land surface. This is remedied by radiometric and geometric correction. In addition, the analyst may want to spectrally enhance the data so that some feature of the landscape is highlighted. An algorithm that differentiates between different plant groups will be applied. Also, the satellite images contain continuous data values over a relatively wide range that need to be grouped into meaningful categories, and a classification procedure will spectrally separate the land cover into these classes. The steps used in preparing the data are illustrated in Figure 3. This diagram also shows the quantitative and qualitative analysis steps that will be applied to the data.

A. *Radiometric Correction*

The first preprocessing step involves correcting for noise and motion in the satellite sensor which cause inaccuracies in the representation of the earth's surface. Sensor noise occurs when the detector does not record correctly the radiance received

Figure 3. Sequence for Image Preparation and Analysis



from the earth's surface. This is due to calibration errors in a detector. The resulting noise is manifested as an entire individual scan line appearing darker or brighter than surrounding lines. "Sixth-line striping" occurs in some earlier Landsat-1, -2, and -3 MSS data as a result of “small differences in the sensitivities of detectors within the sensor” (Campbell, 1987). Much of this noise was corrected with a procedure called destriping (ERDAS, 1994), in which histograms are made for each scan line. These histograms are then averaged for each group of six lines so that their distribution curves more closely match.

The multispectral scanner on board the Landsat platform sweeps from west to east as it records the earth’s reflected energy. During each sweep the earth is continually rotating beneath the satellite (Lillesand and Kiefer, 1987), which results in a shifting of the scan lines so that the arrangement of pixels recorded by the satellite does not represent the pixels’ relative position correctly. Errors resulting from sensor motion were corrected for with a procedure called deskewing (ERDAS, 1994). The 1984 and 1991 MSS images were deskewed by the U.S. Geological Survey’s Earth Resources Observation Systems (EROS) Data Center.

The next radiometric correction performed was to convert the raw digital sensor values to radiance values. Satellite sensors such as Landsat MSS measure the total radiance emitted from a particular ground target as seen at the top of the atmosphere, convert this radiance to a digital count value, and then transmit them to ground stations, where subsequent processing rescales the data to 7-bit binary data (Jensen, 1986a) (see exceptions below). The digital numbers (DNs) recorded by the sensor "do not quantitatively represent real physical values and are used only for convenience in computer processing of the data" (Robinove, 1982). The raw DNs vary between sensors and, in a single sensor, over time, resulting in inaccuracies in image comparisons.

Earth Observation Satellite (EOSAT) Company's Landsat Technical Notes publication (Clark, 1986) provides values for radiance conversion of DNs where the gain and offset values are not available from the header tape. The method has been proven effective (EOSAT, 1994). The equation is expressed as:

$$L_\lambda = LMIN_\lambda + (LMAX_\lambda - LMIN_\lambda / QCALMAX) * QCAL \qquad \text{(Eq. 1)}$$

where

L_λ	= Spectral radiance
$LMIN_\lambda$	= Spectral radiance at QCAL = 0 (sensor offset)
$LMAX_\lambda$	= Spectral radiance at QCAL = QCALMAX (sensor gain)
QCALMAX	= Range of rescaled radiance in units of DN
QCAL	= Calibrated scaled radiance in units of DN

QCALMAX are 127 DN (7 bits) for all MSS data except Band 4 for Landsat-1 to -3 acquired before February 1, 1979 and Landsat-4 MSS data processed before October 22, 1982, which have a QCALMAX of 63 DN (6 bits) (Clark, 1986). The gain and offset values are shown in Appendix B.

The radiance values derived from the satellite digital numbers must take into account the effect of the atmosphere on the sensed energy. The radiance received by the sensor is actually indicative of the radiance at the top of the atmosphere and not of the ground surface itself. But, for earth resource monitoring and analysis it is necessary to examine only the spectral response of the earth's surface, and therefore the radiance must be adjusted for atmospheric attenuation. The atmosphere scatters and absorbs electromagnetic energy, which affects the radiance emitted into space. Absorption is less of a factor since Landsat spectral bands are in atmospheric windows where absorption by gases is minimal. Furthermore, since water vapor has the highest absorbency, using scenes that have low haze conditions lessens this effect. Atmospheric scattering, however, has a larger impact on radiance values than does water vapor absorption. "Scattering causes the atmosphere to have a brightness of its own" (Campbell, 1987).

To account for this atmospheric attenuation, the *Chavez power law relative scattering model* (Chavez, 1988) was applied to the radiance values. The Chavez model is "an improvement to existing dark-object subtraction techniques that derive the correction DN (digital number) values solely from the digital data with no outside information" (Chavez, 1988). This model accounts for the spectral band dependency of the atmospheric influence on electromagnetic energy. It is a *relative* model that is based on the laws of physics and the relative scattering models of Rayleigh and Mie (Chavez, 1988). Different corrections are applied based on whether the atmosphere is very clear, clear, moderate, or hazy, and for different spectral bands, since, based on Rayleigh's Law, the effect of scattering is greater in the shorter wavelengths (See Table III). The very clear conditions are based on Rayleigh's Law. The condition of the atmosphere is determined by the histogram of DN values, indicating more haze as the lowest DN value becomes higher.

With the added effect of the atmosphere, dark objects will usually be recorded with a higher value when they should be near zero. These dark-object values "represents the DN value that must be subtracted from the particular spectral band to remove the first-order scattering component" (Chavez, 1988). A histogram of band 1 was produced for each image to obtain a starting subtraction haze value. Band 1 was used since its blue-green spectral range illustrates the impact of the atmosphere the most. The *Chavez scattering model* is then applied to the data.

Table III. Relative Scattering Models Used with Various Atmospheric Conditions

Atmospheric Conditions	Relative Scattering Model
Very Clear	λ^{-4}
Clear	λ^{-2}
Moderate	λ^{-1}
Hazy	$\lambda^{-.7}$
Very Hazy	$\lambda^{-.5}$

The starting haze value (SHV) from band 1 is then used to calculate predicted haze values for the other spectral bands, termed DN(OUT), which are shown in Appendix C. The equation is as follows:

$$\mathrm{DN(OUT)} = (\mathrm{SHV1} * \mathrm{HAZE}) * \mathrm{NORM} + \mathrm{OFFSET} \qquad \text{(Eq. 2)}$$

where

SHV1	= Starting Haze Value of MSS band 1
HAZE	= Multiplication factor to predict haze value
NORM	= Normalized gain factor (computed by dividing the band 1 value into the gain value ($LMAX_\lambda$) of the other bands)
OFFSET	= Offset value ($LMIN_\lambda$)
DN(OUT)	= Predicted haze value

The HAZE values are shown in Appendix D and the NORM and OFFSET values are shown in Appendix B.

The starting and predicted haze values then need to be converted to radiance values so that they may be used with the radiance equation to subtract out the influence of the atmosphere. Each haze value is inserted into the radiance equation (Eq. 1). The radiance haze value that results is for zero percent reflectance. However, this assumes that objects are being sensed that have no reflectance; i.e., a black body. Since black bodies do not exist on the earth's surface, a one percent radiance is assumed for dark-objects, which is more realistic (Chavez, 1994). Each radiance haze value was multiplied by .99 to obtain a final radiance haze value, which are shown in Appendix E.

In order to compare remotely sensed images using two or more scenes, it was desirable to convert the radiance values into reflectance values. "For relatively clear Landsat scenes, a reduction in between-scene variability can be achieved through a normalization for solar irradiance by converting spectral radiance . . . to effective at-satellite reflectance, or in-band planetary albedo" (Clark, 1986). This will account for the earth-sun distance, the elevation of the sun, and the incoming energy (incident solar radiation). The reflectance received by the satellite is given by (Clark, 1986):

$$p_p = \pi * L_\lambda * d^2 / ESUN_\lambda * \cos\theta_s \qquad \text{(Eq. 3)}$$

where

p_p = Unitless effective at-satellite planetary reflectance

L_λ = Spectral radiance at sensor aperture in $mW * cm^{-2} * ster^{-1} * mm^{-1}$

d = Earth-Sun distance in astronomical units from nautical handbook

$ESUN_\lambda$ = Mean solar exoatmospheric irradiances in mW * cm^{-2} * mm^{-1}

θ_s = Solar zenith angle in degrees from Appendix A

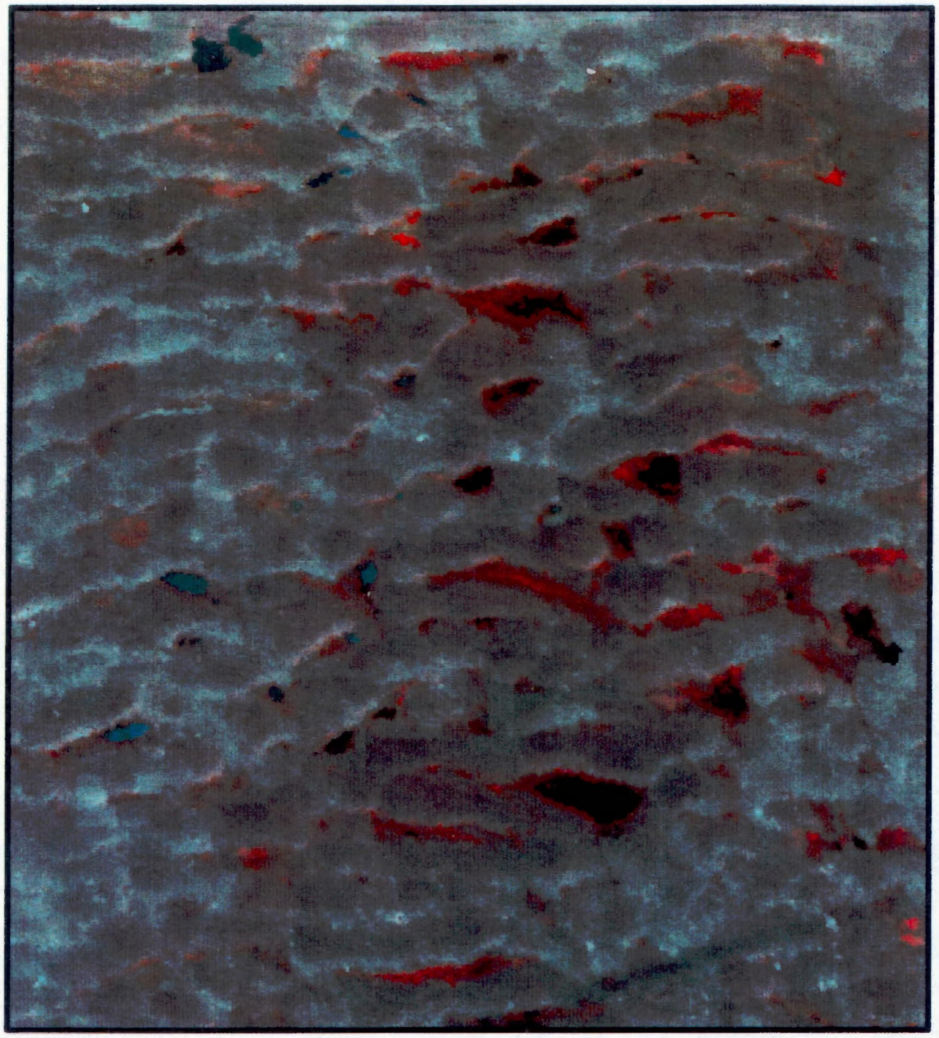
The solar zenith angle is found by subtracting the sun elevation value, obtained from the tape header, from 90 degrees. The $ESUN_\lambda$ values are found in Appendix F.

The implementation of the radiance, atmospheric, and reflectance equations were performed using a single algorithm. Each band for each image had its own equation, generated as follows:

$$\text{Reflectance} = ((\text{QCAL} * ((\text{LMAX}_\lambda - \text{LMIN}_\lambda) / \text{QCALMAX}) + \text{LMIN}_\lambda - \text{RADIANCE HAZE VALUE}) * \pi * d^2 / (\text{ESUN}_\lambda * \cos\theta_s)) * 100 \qquad \text{(Eq. 4)}$$

where, π equals 3.141592654 and multiplying by 100 converts the values to percent reflectance. The final reflectance images are shown in Plates 1 through 6. The colors illustrated in these images represent the amount of reflectance in each spectral band for an individual pixel. For example, red indicates high reflectance in the near-infrared (band 4) and low reflectance in the visible (bands 1 and 2).

Plate 1. Reflectance Image, Bands 4, 2, and 1: 1973



Scale

Kilometers 5 0

Miles 5 0

1 : 233440.43

Legend

Band 4

Band 2

Band 1

Plate 2. Reflectance Image, Bands 4, 2 and 1: 1976

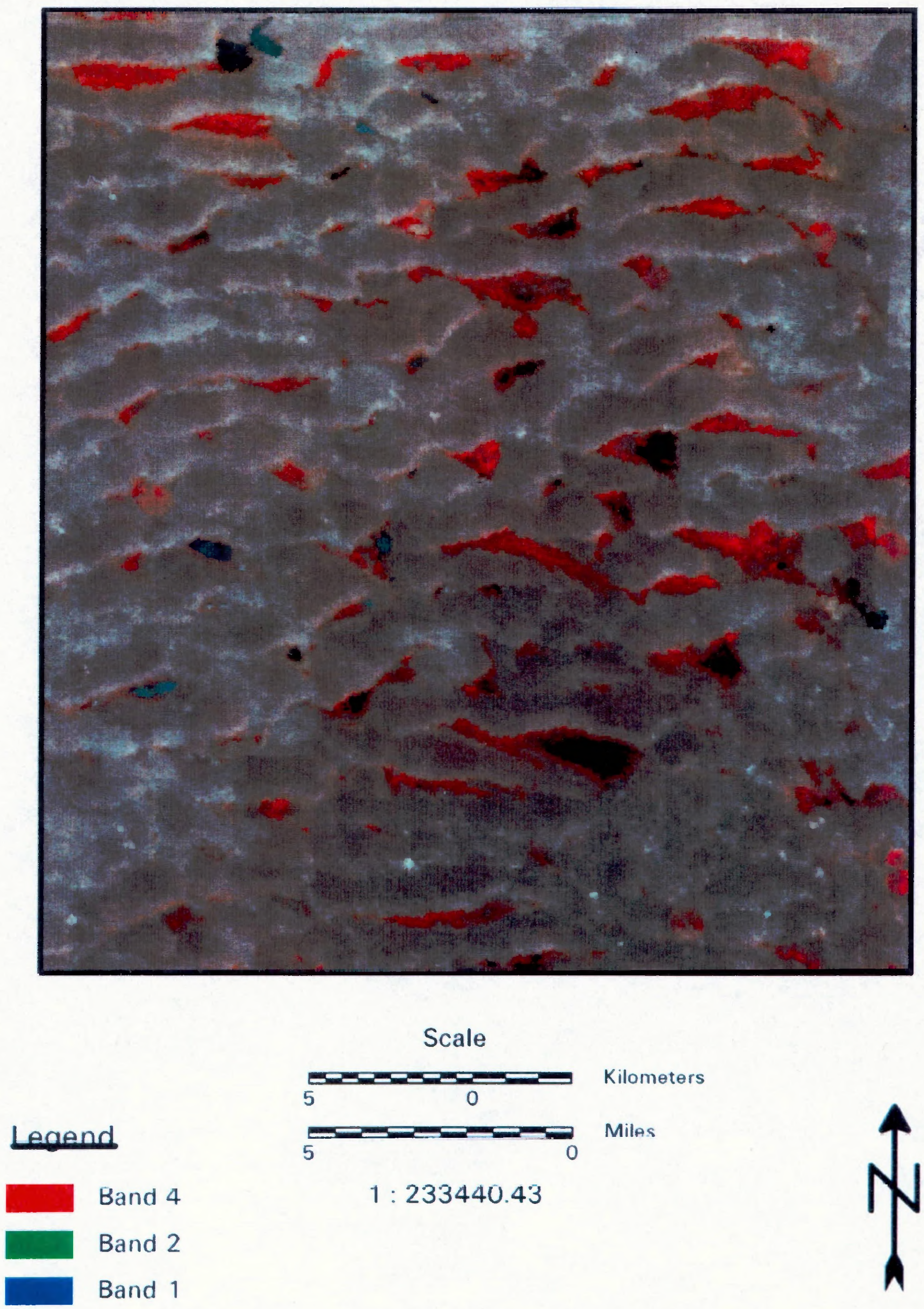
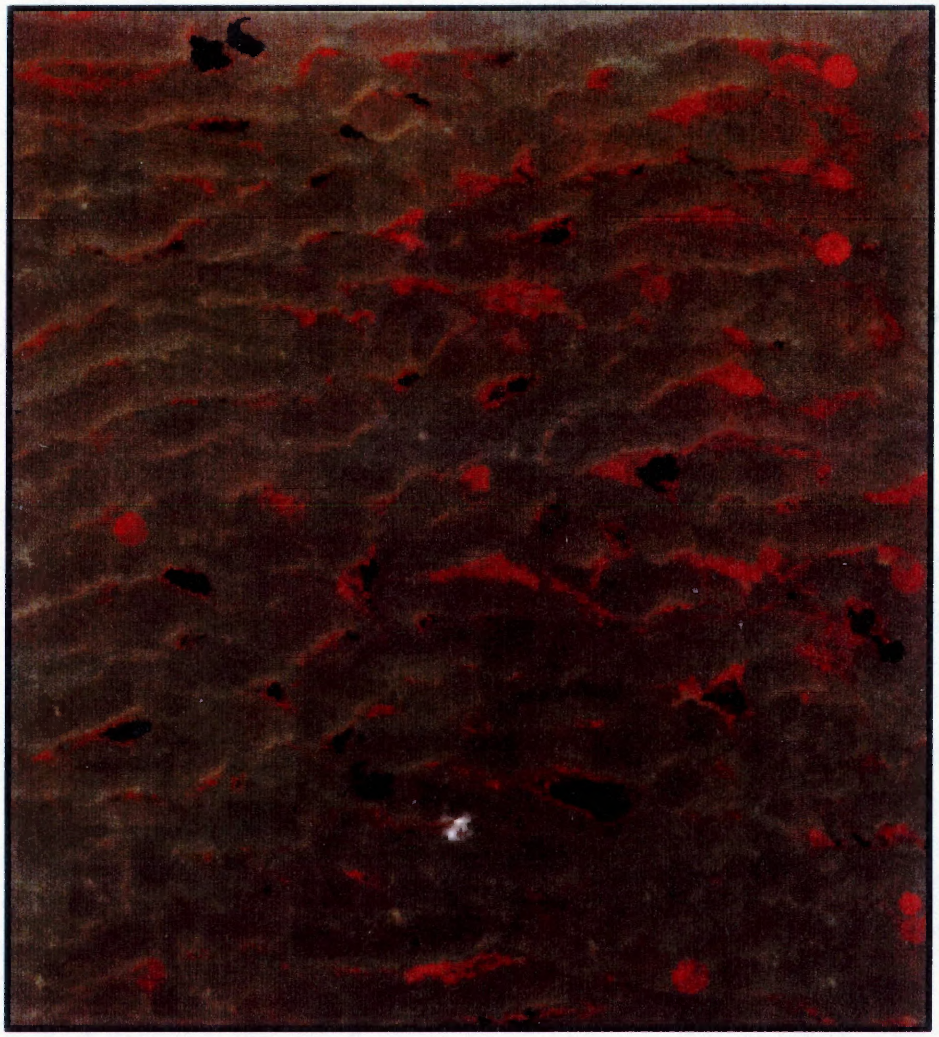


Plate 3. Reflectance Image, Bands 4, 2, and 1: 1977



Scale

Kilometers

5 0

Miles

5 0

1 : 233440.43

Legend

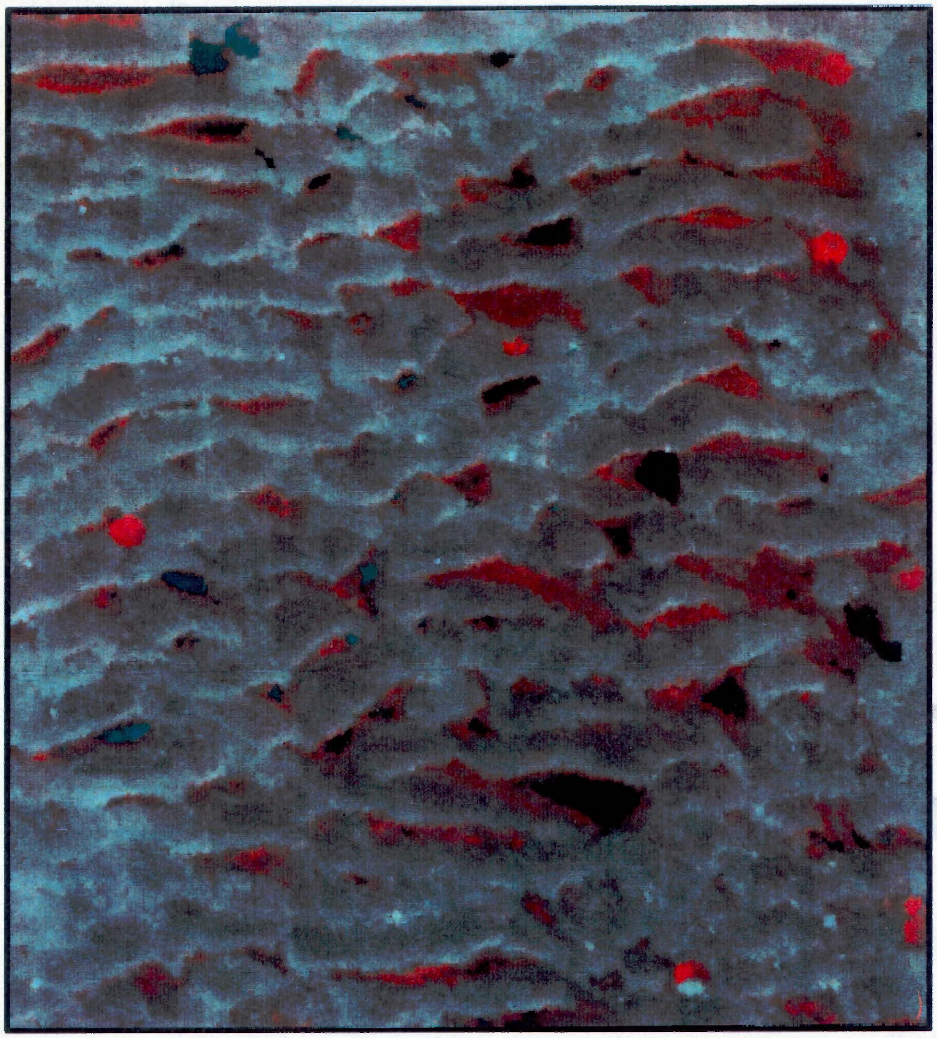
Band 4

Band 2

Band 1

N

Plate 4. Reflectance Image, Bands 4, 2, and 1. 1978



Scale

Kilometers

5 0

Miles

5 0

1 : 233440.43

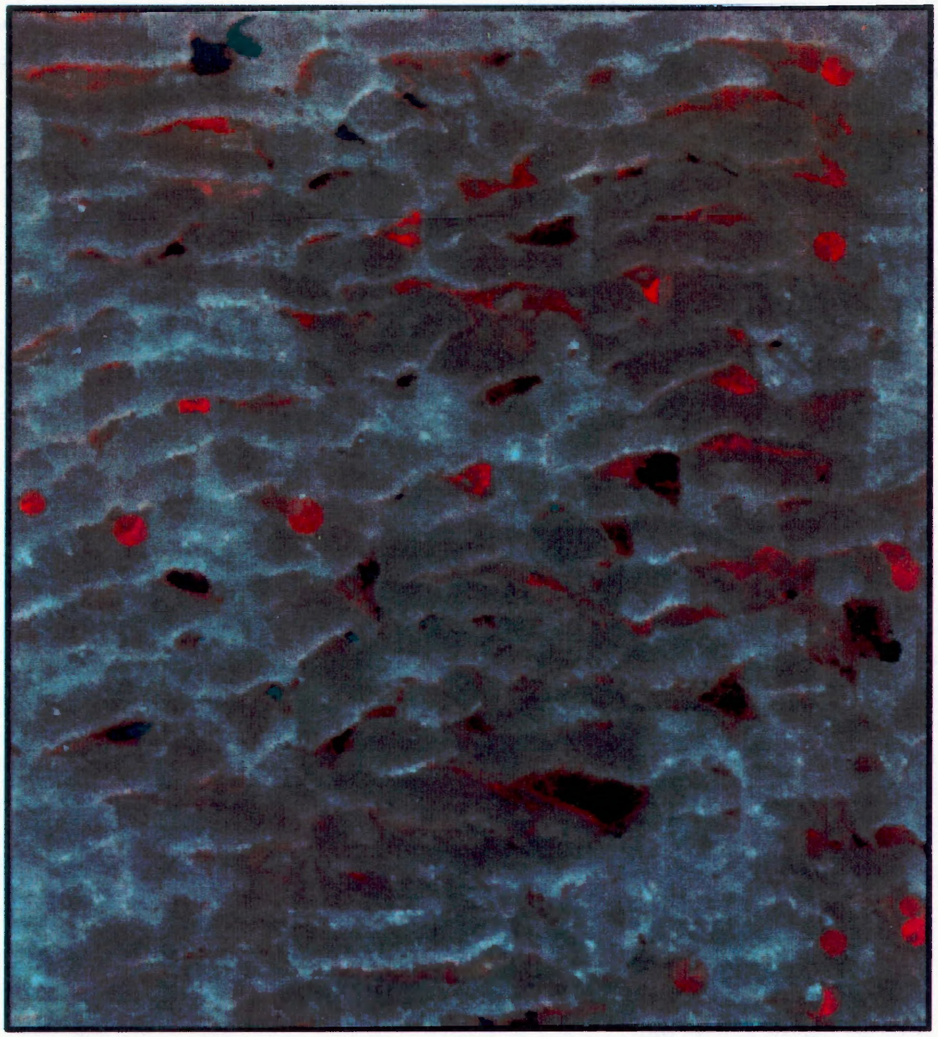
Legend

Band 4

Band 2

Band 1

Plate 5. Reflectance Image, Bands 4, 3, and 1. 1984



Scale

Kilometers

5 0

Miles

5 0

1 : 233440.43

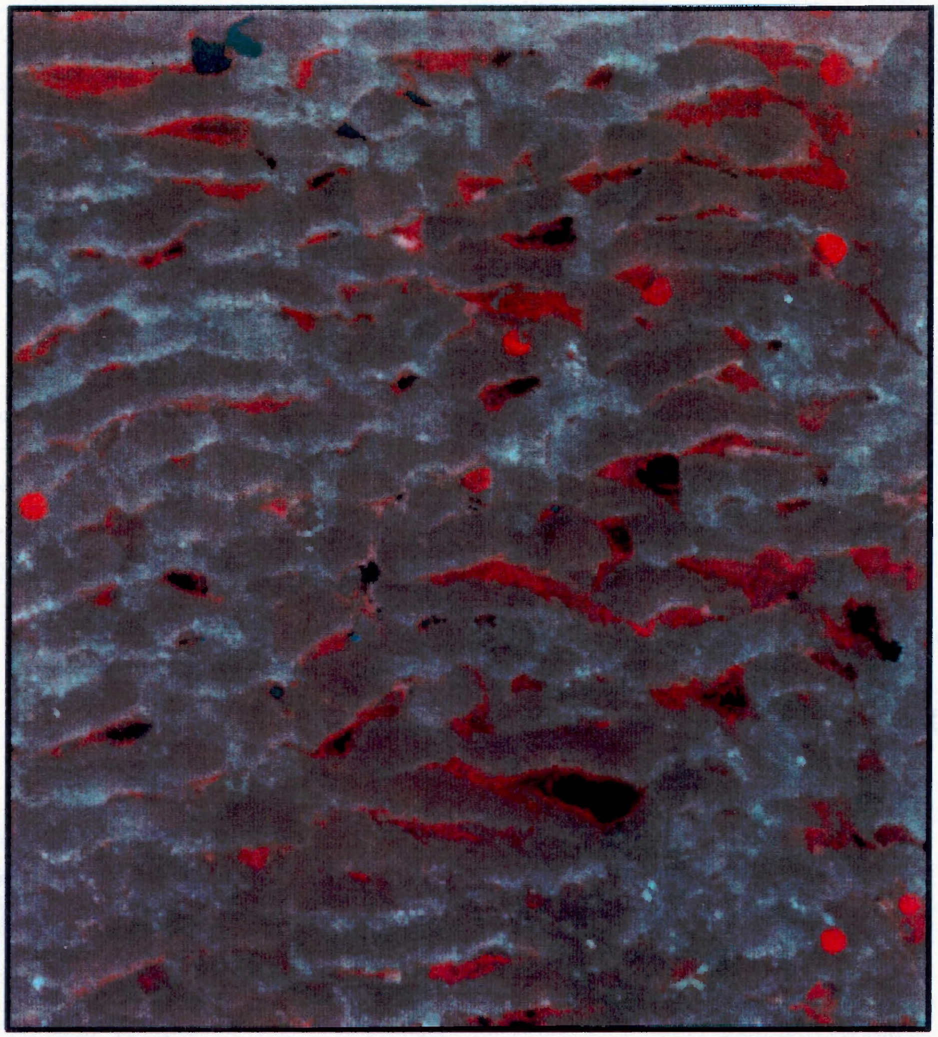
Legend

Band 4

Band 2

Band 1

Plate 6. Reflectance Image, Bands 4, 2, and 1: 1991



Scale

Kilometers
5 0

Miles
5 0

1 : 233440.43

Legend

Band 4
Band 2
Band 1

N

B. *Vegetation Enhancement*

Once radiometric preprocessing was complete, a data preparation procedure was conducted to enhance the spectral characteristics of the land surface. Probably the most widely used remote sensing measure of vegetation characteristics is the normalized .difference vegetation index (NDVI). The NDVI is derived as a ratio of the near-infrared and red spectral bands and is expressed as:

$$NDVI = (NIR\text{-}RED) / (NIR+RED) \qquad \text{(Eq. 5)}$$

Band 4 is used as the near-infrared band (NIR) since it covers the portion of the spectrum where vegetation reflectance is greater, and band 2 is used to represent the red portion (RED) of the spectrum.

NDVI has been directly related to biomass in plants as well as transpiration and thus water stress (Cohen, 1991; Running and Nemani, 1988), photosynthesis (Running and Nemani, 1988), and net primary production (Loveland *et al.*, 1991). The transformation has the ability to depict these characteristics due to the different spectral response of vegetation in the red and near-infrared portions of the radiometric spectrum. Chlorophyll causes plants to absorb radiation in the red portion of the spectrum and reflect energy in the near-infrared portion of the spectrum (Campbell, 1987).

However, the NDVI equation produces negative values when the red band values are higher than near-infrared values. For example, in the area used for this study, water that has relatively few contaminants would reflect higher in the red portion of the spectrum than in the near-infrared since water reflects near zero in the infrared. These negative values may produce complications during subsequent image processing and data analysis. To eliminate the negative values, the transformed vegetation index (TVI) was applied using the results of the NDVI calculations in the following algorithm (Jensen, 1986a):

$$TVI = [(NDVI + 1.5) / ABS(NDVI + 1.5)] * [\sqrt{ABS(NDVI + 1.5)}] \qquad \text{(Eq. 6)}$$

where ABS is the absolute value of the calculation. The transformed images are shown in Figures 4 through 9.

The TVI algorithm produced spectral separability among most land cover classes upon analysis with the reference data. However, the marsh areas had overlapping values with the upland features. Therefore, the upland values for each date were masked out using the classification image data for the corresponding year. This allowed for only the wetland TVI values to remain.

C. *Classification*

Each satellite image has wide-ranging reflectance values. This presents difficulties when trying to understand what land cover the pixel reflectance value represents and in comparing land covers from different dates. Digital image classification assigns pixels with similar reflectance values into a single class that is assumed to represent a particular

Figure 4. Transformed Vegetation Index Image: 1973

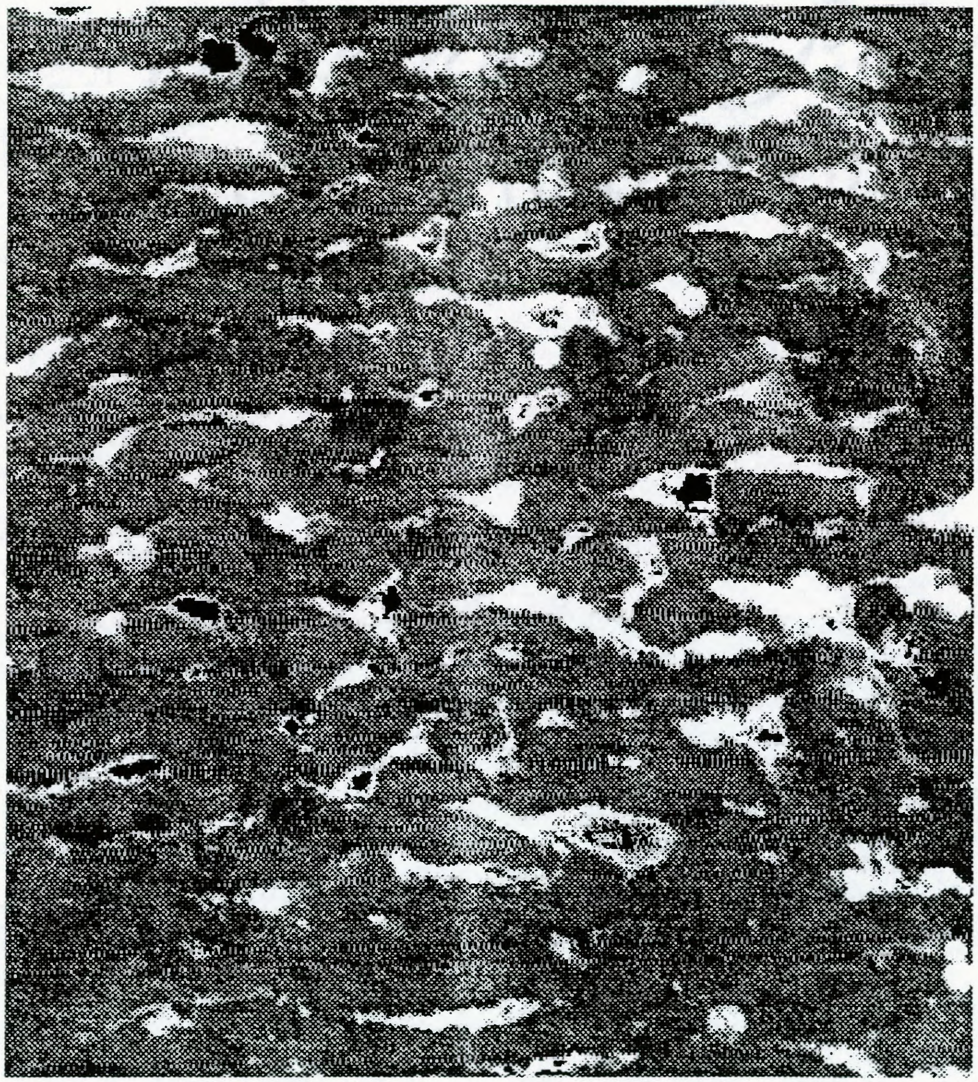
Scale
1 : 233440.43

Legend

TVI Value

Low
Medium
High

Figure 5. Transformed Vegetation Index Image: 1976



Scale
1 : 233440.43

Legend

TVI Value

Low
Medium
High

Figure 6. Transformed Vegetation Index Image: 1977

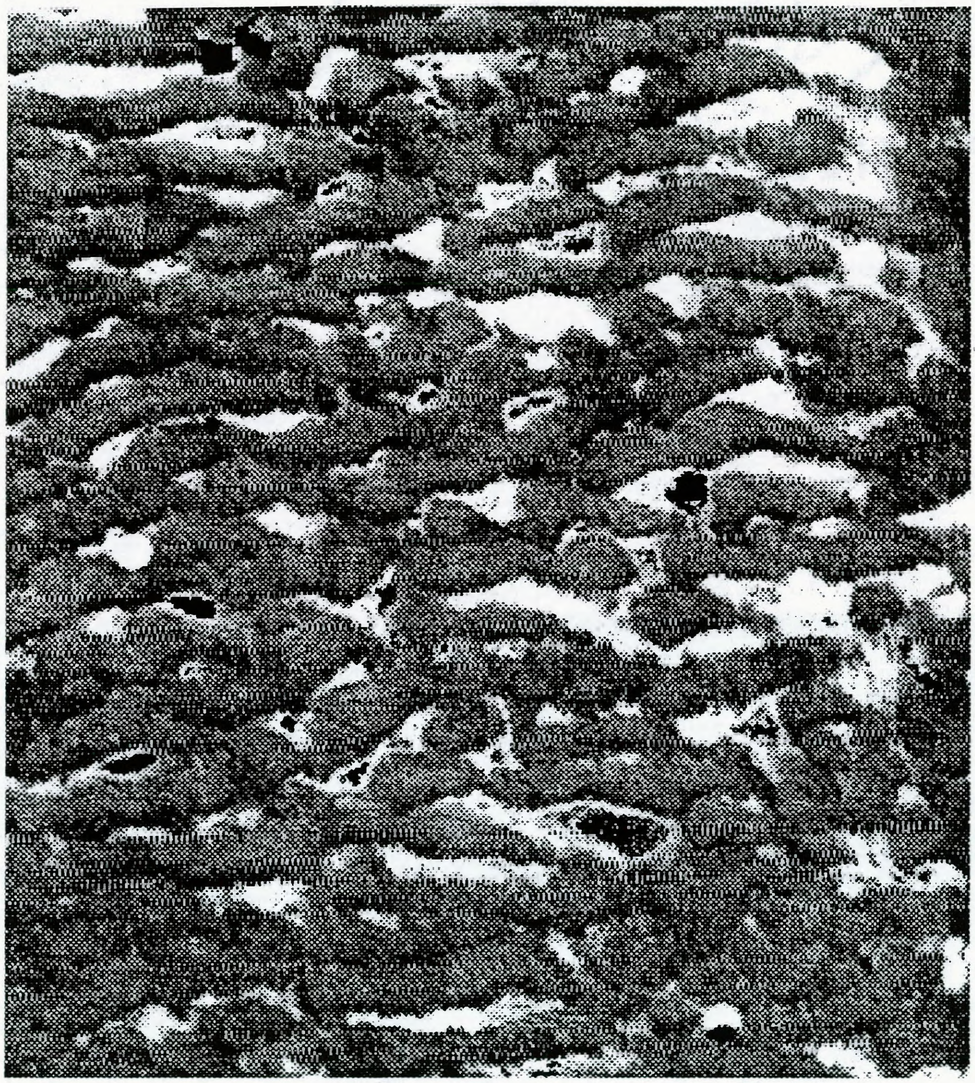
Scale
1 : 233440.43

Legend

TVI Value

Low
Medium
High

Figure 7. Transformed Vegetation Index Image: 1978



Scale
1 : 233440.43

Legend

TVI Value

Low
Medium
High

Figure 8. Transformed Vegetation Index Image: 1984

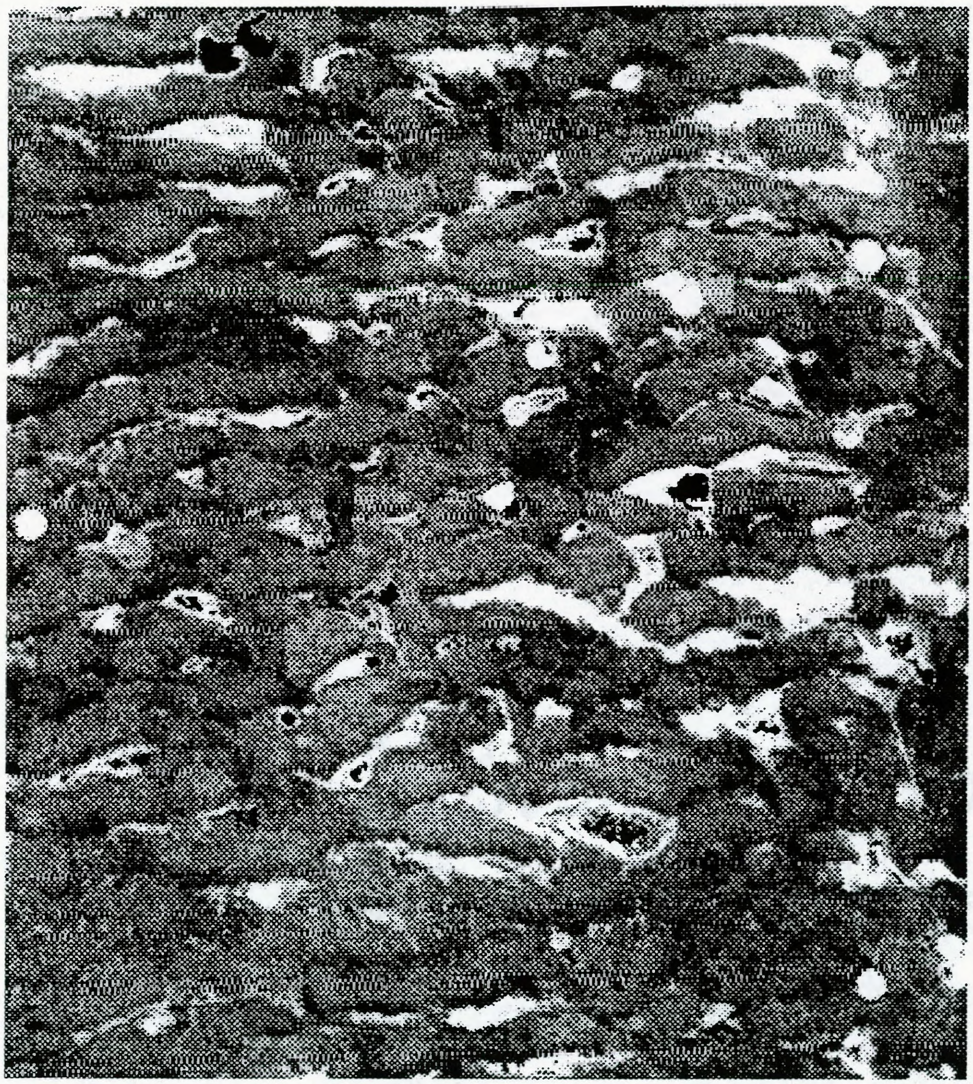
Scale
1 : 233440.43

Legend

TVI Value

Low
Medium
High

Figure 9. Transformed Vegetation Index Image: 1991



Scale
1 : 233440.43

Legend

TVI Value

Low
Medium
High

land cover on the earth's surface. A subset of each image scene was created before classification to reduce the calculations required and to limit the classification to the study area.

A hybrid classification approach was used to offset some of the disadvantages (Campbell, 1987) of using only supervised or unsupervised classification methods. Generally, unsupervised classification allows for minimum user input and for the creation of spectrally differentiated land cover categories that are applicable to conditions throughout the image, while supervised classification allows for more control of the selection of informational classes that are applicable to the area of interest. The ISODATA unsupervised classifier (Duda and Hart, 1973) was used to create signatures for the classification algorithm. ISODATA is a variation on the minimum distance method (Campbell, 1987) and involves repeated passes of the algorithm throughout the image, creating clusters or training samples from all four MSS spectral bands. ISODATA was found by Dinville (1993) to be an effective technique in the classification of wetlands. The signatures developed in ISODATA are then submitted to the maximum likelihood decision rule that performs the final classification. It is a supervised method based on the probability that a pixel belongs to a certain class and takes into consideration the variability of class by using the covariance matrix (ERDAS, 1994).

The classification methodology began by separating out the wetlands, the focus of this study, from the surrounding sandhill uplands. The first step in this procedure was to apply ISODATA to the reflectance conversion images. 60 classes, that is, clusters, were created using a 99% confidence threshold. Several iterations were performed by ISODATA before this level was reached. This research and the research conducted by Dinville (1993) found that using less than 60 clusters would not highlight wetland arcas adequately.

In the second step of separating wetlands from uplands, a composite image was created by overlaying the ISODATA image on a reflectance image made up of bands 2, 3, and 4. This composite image was then statistically and visually analyzed to determine what reflectance values and what areas of the image represented wetland and upland land cover. Topographic maps, Army Corps of Engineers wetland maps, aerial photographs, and the Landsat TM image were used in the visual analysis.

The third step involved creating a mask to exclude the uplands from the classification process. First, the ISODATA image was recoded so that cluster values that corresponded to upland areas were set to zero. A masked image was then produced using the original reflectance image as the input data and the recoded ISODATA image to exclude uplands. The resultant image for each date contained ten to fourteen wetland classes along with the one upland class.

The second procedure in the classification process was to create training samples that would be used in the supervised classification algorithm. First, ISODATA was applied to the masked reflectance images to create fifteen clusters, ignoring zeros (uplands) in the classification. Again, a confidencc threshold of 99% was used to increase the spectral separability of wetland classes. Second, statistical and visual analysis was performed to determine to which of the three wetland classes—water, marsh, subirrigated meadow—each of the 15 clusters belonged. This was done by using the Corps' wetland maps from 1978 as the ground truth for the 1978 image classification. The clusters from the 1978 ISODATA image were assigned to one of the wetland categories based on this reference source and on the Corps' documentation on the spectral properties. This merging of signatures was then done for each of the other image dates based on the spectral properties defined by the 1978 signature merging. The final three wetland signatures for all image dates had the same cluster numbers merged together and covered similar ranges of values for the red and near-infrared portions of the electromagnetic spectrum; that is, cluster 1 was used as the signature for water, cluster 2 for marsh, and clusters 3 through 15 for subirrigated meadow.

The third and final procedure in the classification process involved submitting the ISODATA wetland signatures to the maximum likelihood supervised classification algorithm, using the masked reflectance data as the input image. This produced a black and white image. Colors were then assigned to each land cover class. Statistical analysis and a visual comparison to the Corps' wetland maps was conducted. The final classification images are illustrated in Plates 7 through 12.

D. *Geometric Correction*

It is important in multitemporal studies to accurately detect the changes that have occurred from one date to another. "If accurate registration between images is not

Plate 7. Land Cover Classification Image: 1973

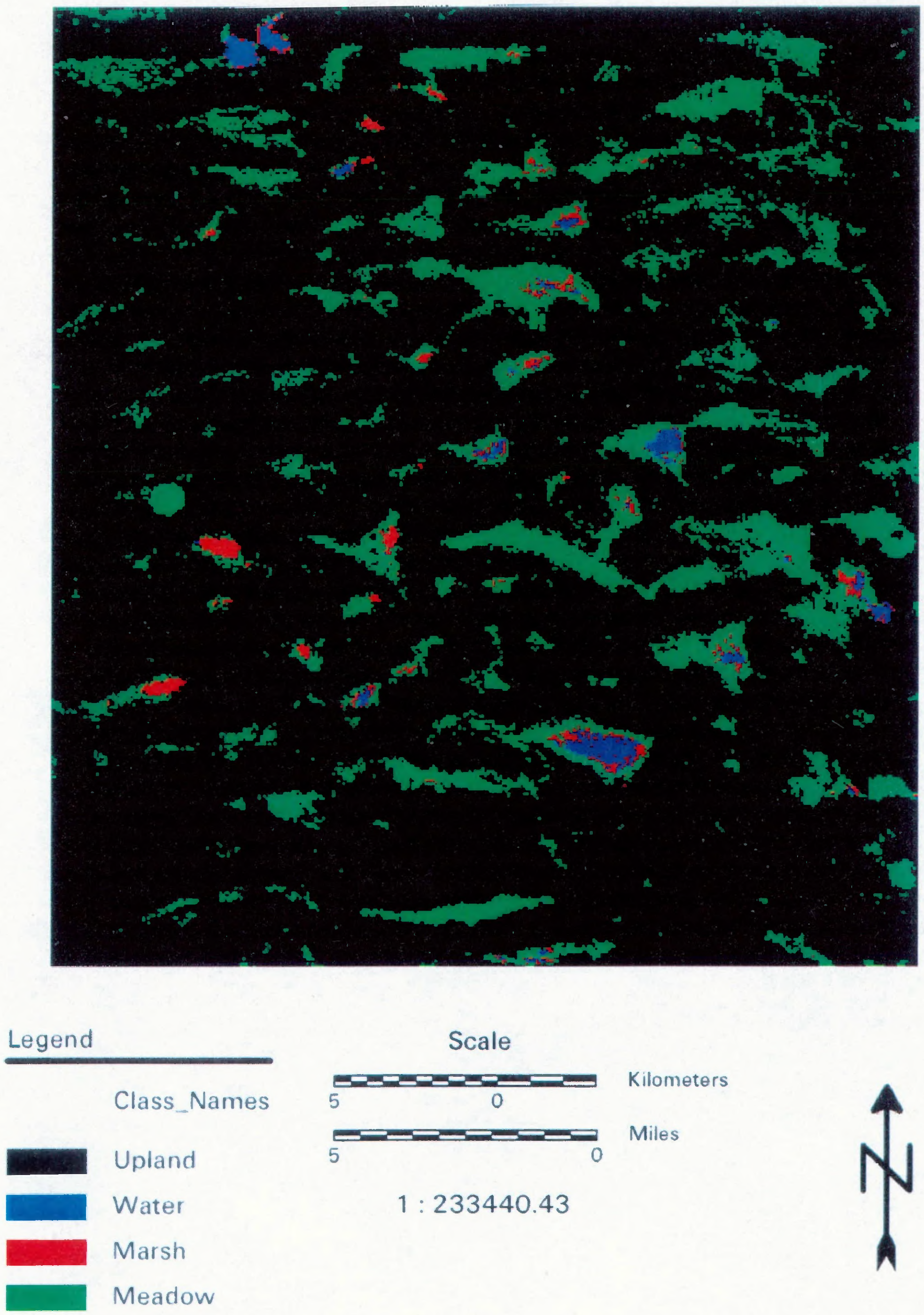


Plate 8. Land Cover Classification Image: 1976

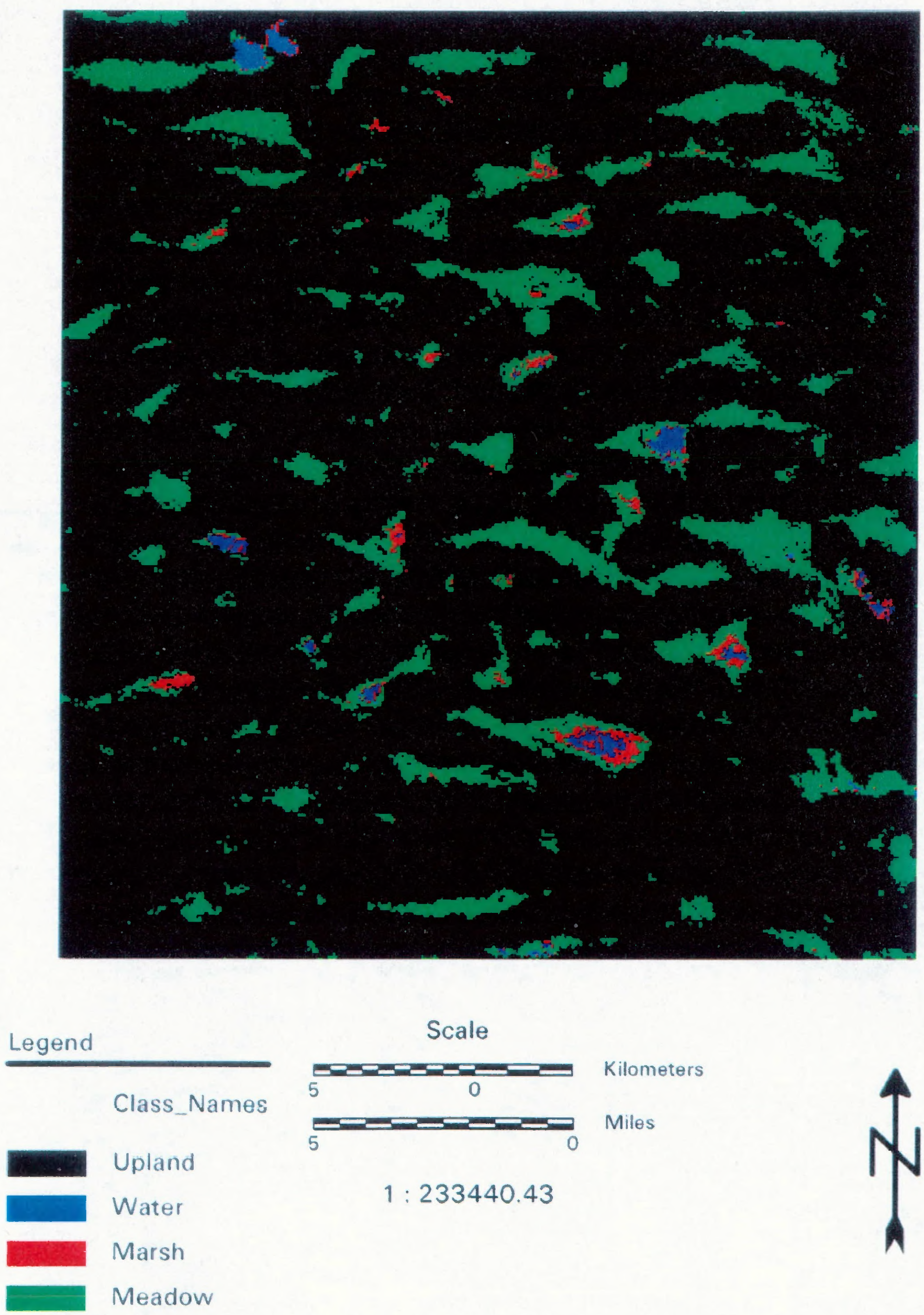


Plate 9. Land Cover Classification Image: 1977

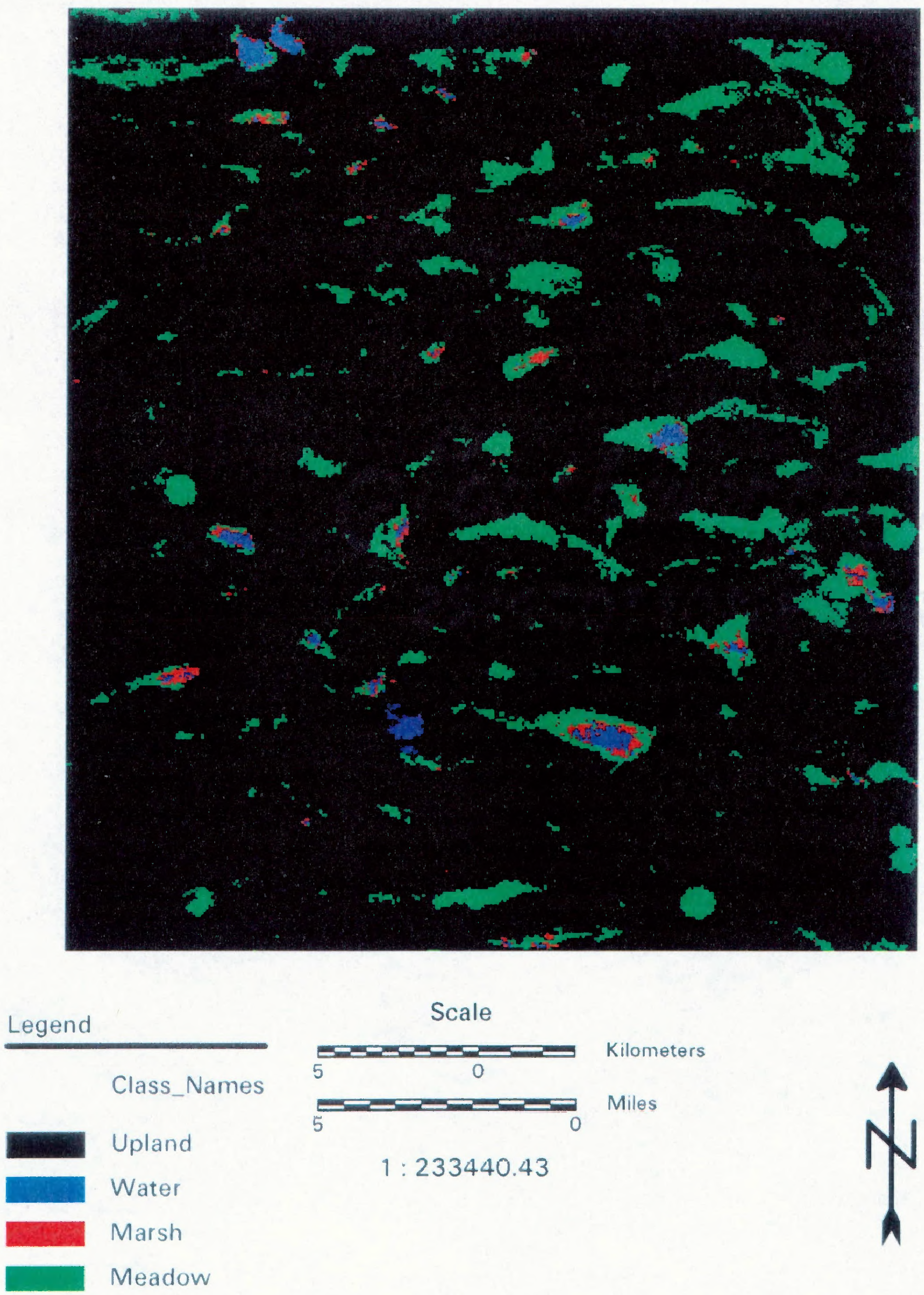
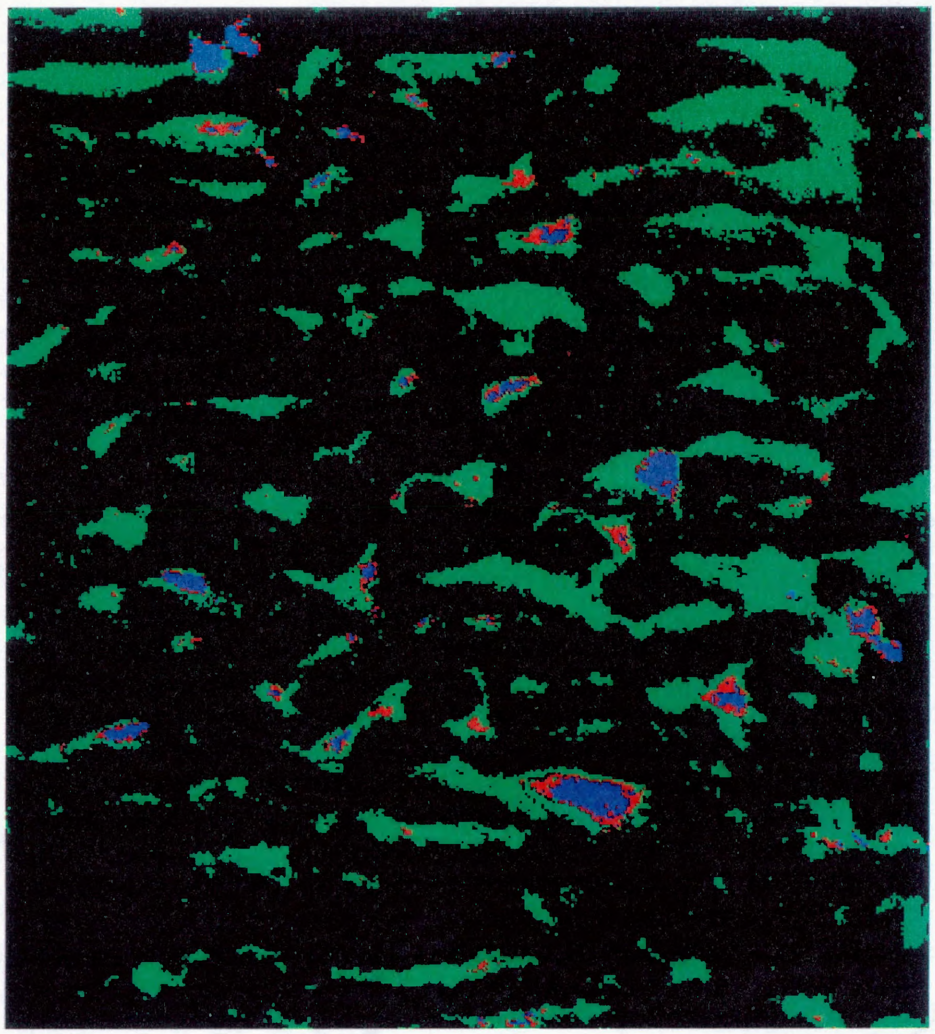


Plate 10. Land Cover Classification Image: 1978



Legend

Class_Names

- Upland
- Water
- Marsh
- Meadow

Scale

5 0 Kilometers

5 0 Miles

1 : 233440.43

N

Plate 11. Land Cover Classification Image: 1984

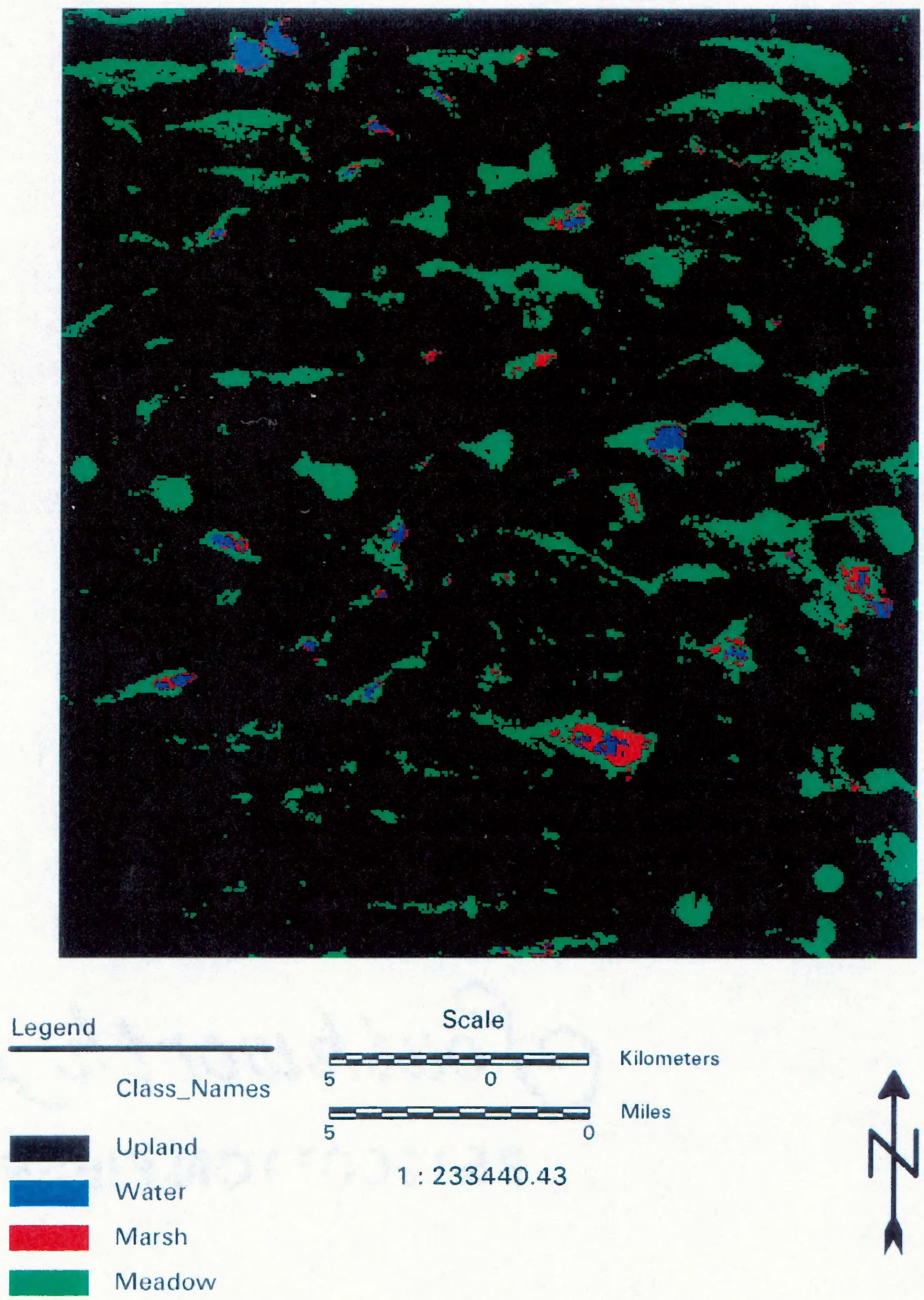
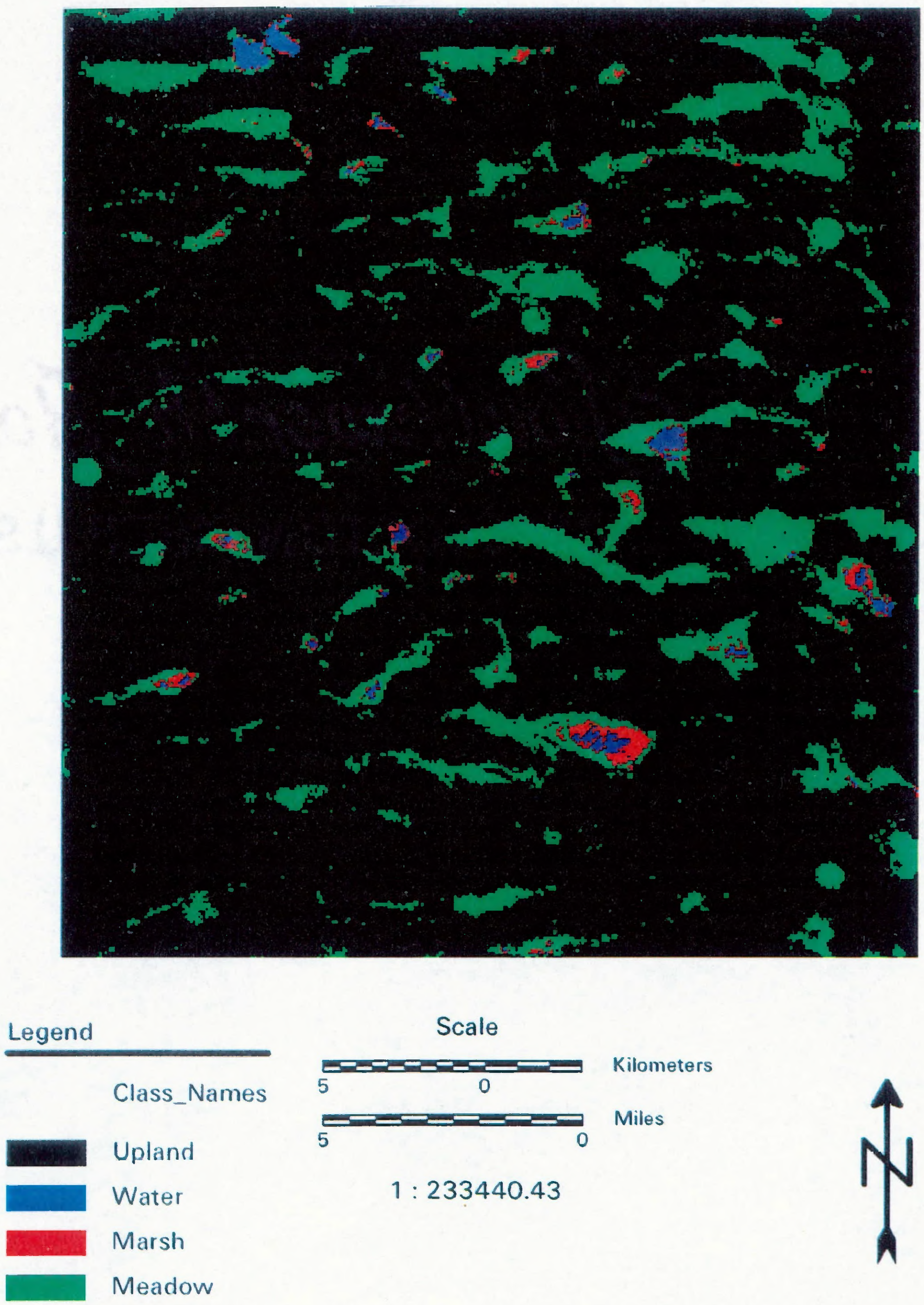


Plate 12. Land Cover Classification Image: 1991



achieved, then spurious differences will be detected, arising merely because different locations are compared instead of differences in properties at the same location between one time and another" (Townshend *et al.*, 1992). Due to orbital characteristics within and between satellite sensors the data file coordinates for each image are different. In addition, the earth's spherical surface cannot be accurately represented on a flat surface (such as a paper map or computer screen). To correct for both of these problems, rectification must be performed. Rectification, in this case, referenced the images to a Universal Transverse Mercator (UTM) map projection, making the images more nearly planimetric (Campbell, 1987; Jensen, 1986a). This will allow for pixels representing the same land surface to be compared. In addition, accurate measurements of area are possible (Jensen, 1986a) and the assessment of change will be more reliable. Dinville (1993) obtained sub-pixel accuracy in the Nebraska Sandhills using Landsat MSS and other researchers, including Jensen (1983) and Fung and LeDrew (1988), have obtained sub-pixel accuracy using Landsat MSS.

The procedure consisted of using the Landsat TM image, which had already been rectified to UTM coordinates, along with topographic maps, wetland maps, and aerial photographs that aided in registering the Landsat MSS images. Ground control points (GCPs) that were evenly distributed throughout the MSS images and coincided with identifiable features were selected. The GCPs had to extend beyond the perimeter of the study area boundary since the natural environment of the Sandhills has relatively few spectrally stable features. Even roads and ranch buildings are not identifiable at the MSS spatial resolution of 79 by 79 meters. Features that were used included edges of lakes and marshes where there was an abrupt transition from wetland to upland due to topographic relief.

Over twenty ground control points were initially selected for each image. Some of these GCPs were found to have experienced too much change between dates so that their registration with the same ground location was in doubt. These were not used in the registration process. A subset that included the GCPs was created to limit the rectification to the study area. Twenty GCP coordinates were entered into the GCP editor in IMAGINE for each image. In order to have the images overlay correctly after registration, the upper left and lower right coordinates had to be exactly the same. This was accomplished by using GCPs that would constitute these corners.

The 1976 Landsat MSS image was registered to the 1991 Landsat TM image using a second order transformation. In order to obtain a positional accuracy to within one pixel, the root mean square (RMS) error needed to be within 0.5 for the entire image. RMS error measures the geometric distortion not corrected for during the initial rectification (Jensen, 1986a). Individual GCPs that had an RMS error significantly higher than 0.5 for the x, y, or both coordinates, were corrected or eliminated based on closer examination of the MSS and TM images. Seventeen GCPs were used in the final rectification process. Total RMS error of less than 0.5 was obtained for the 1976 image.

The output grid/image needs to be assigned reflectance values found within the original input grid/image. Nearest neighbor resampling allows each output pixel to receive its value from the nearest point on the input image (Campbell, 1987). This method is the least detrimental resampling technique: original values are retained for the entire image, although some individual pixels may be assigned wrong values (Campbell, 1987; Jensen, 1986a). The 1976 image was resampled to a 79 by 79 meter pixel size. The rest of the Landsat MSS images were registered to the rectified 1976 Landsat MSS image using a second order transformation and resampling to 79 by 79 meter pixels. This assured accurate overlay of all the MSS images.

After rectification was complete, each image contained the exact same area, except the 1984 and 1991 MSS images contained some pixel values located outside the other images' areal extent. However, the file coordinates and UTM coordinates for the 1984 and 1991 MSS images coincided with the other images. The reason for this is that the Landsat-4 and Landsat-5 satellites have an orbiting altitude of 705 kilometers and the earlier satellites orbited at 900 kilometers. A subset of all the rectified images was performed so that each image contained the same number of pixels covering the exact same area with the same pixel size. The spectral and land cover data were then exported to another computer system using export procedures described in Appendix G. An accuracy assessment of the registration procedure will now be examined in order to indicate possible error in the data analysis results that is due to positional error. Later, the change detection methodology and results will indicate the type of changes that are occurring in the wetlands and the extent of these changes, both temporally and spatially.

Chapter VI

ACCURACY ASSESSMENT

The accuracy of the classified image had to be quantitatively assessed in order to judge the reliability of subsequent data analyses. This involved comparing the classified data to reference data that is assumed to be accurate. In the best of circumstances, *in situ* data is collected at the same time as the satellite overpass of an area. However, because only archived data were used, it was not possible to collect *in situ* data. The reference data used were U.S. Army Corps of Engineers wetlands maps of the study area. These maps were produced using a June 6, 1978 Landsat MSS satellite image, making *in situ* observations at sample locations in the Nebraska Sandhills, photographic interpretation, and the examination of the spectral characteristics of the land cover (Turner and Rundquist, 1980). National Wetland Inventory maps were available, but they did not recognize subirrigated meadows as a wetland class and they categorized marsh and open water differently than Landsat MSS studies.

The Corps of Engineers' wetland maps contained three wetland classes: water, marsh, and subirrigated meadow. These classes were also used in this study. The June 6, 1978 image was also used as part of the data set for this research study and the classification produced from it was compared to the Corps of Engineers' maps. The other classified images were not directly assessed for accuracy. The theory is that if the accuracy of one classified image is known and all other images were classified in the same manner, it can be reasonably assumed that the accuracy of all are similar. Dinville (1993) used this approach in his classification evaluation.

The sampling method consisted of establishing a 34 by 30 pixel grid over the original reflectance image of the study area (338 by 390 pixels). Areas located within each grid were selected using the Army Corps of Engineers maps that were overlaid on top of topographic base maps. The UTM coordinates from the base maps were used to determine the file coordinates of the satellite image. Areas containing from 4 to over 500 pixels of each land cover class of the Corps maps located within a grid were selected. These samples could then be compared to the reference data.

This method is not a true accuracy assessment and it has its limitations. First, only the 1978 MSS image classification is assessed, not all six images. Although the other image classifications may have similar accuracy, the exact error is not known and this may influence the validity. The classification methodology may have worked well for one image, but other image dates may have had environmental conditions that do not lend well to this classification procedure, resulting in misclassification. In addition, during the sampling procedure, only pixels of known Corps of Engineer's classes were used. Thus, pixels located on the outer edges of a land cover class were not selected because the 79 by 79 meter pixels limited the precision. The precision was also hampered by the differing orientation of pixel rows and columns in the Corps maps and the classified images from

ERDAS Imagine. The former were oriented NW-SE while the latter were oriented E-W. Finally, there was likely to be bias in the selection of the samples since the analyst was familiar with the classified product.

Still, this is the best method available for the available data. The grid sampling method ensures representation throughout the study area and a recognized reference source was used. The accuracy assessment generally measures how well the 1978 classified image compares to the classification maps of the Wetlands Inventory of the Omaha District.

The classified land cover data were compared to the reference data by the use of an error matrix generated by a computer program written in the 'C' programming language. [See Appendix H.] Several accuracy indices result from this cross-tabulation and are explained below. The results are shown in Table IV. The agreement between the two data sets is indicated by the major diagonal (Story and Congalton, 1986). The null hypothesis states that the classified image is not of acceptable accuracy; it will be tested by the Kappa coefficient.

A. *Entire Image Accuracy Assessment*

The accuracy of the entire image was measured by the overall accuracy and the Kappa coefficient of agreement. The overall accuracy is calculated by dividing the total number of correctly classified samples (major diagonal total) by the total number of

Table IV. Accuracy Assessment Results

a. Land Cover Assessment*

Land Cover 1976 Image/ Reference Data	Water	Marsh	Meadow	Upland	Total
Water	286	4	0	0	290
Marsh	0	16	2	0	18
Meadow	0	0	2733	19	2752
Upland	0	2	112	25174	25288
Total	286	22	2847	25193	28348

*Based on number of pixels.

b. Percent Land Cover

Land Cover 1976 Image/ Reference Data	Water	Marsh	Meadow	Upland
Water	0.01009	0.00014	0.00000	0.00000
Marsh	0.00000	0.00056	0.00007	0.00000
Meadow	0.00000	0.00000	0.09641	0.00067
Upland	0.00000	0.00007	0.00359	0.88803

c. Individual Category Agreement

Statistic	Water	Marsh	Meadow	Upland
User's	98.62	88.89	99.31	99.55
Producer's	100.00	72.73	96.00	99.92
Conditional Kappa (User's)	98.61	88.88	99.23	95.95
Conditional Kappa (Producer's)	100.00	72.71	95.97	99.30

d. Entire Image Accuracy

Overall = 99.59
Kappa = 97.52

samples. "It weights each category according to the number of samples in that category [,therefore] it has a tendency to be biased toward the category with the larger number of samples" (Fung and LeDrew, 1989), which was the upland category for this study area. The overall accuracy was 99.5%. Alternatively, the Kappa coefficient is a measure of the actual agreement minus chance agreement (indicated by the row and column marginals) (Fung and LeDrew, 1989). Kappa is computed as:

$$K = M\Sigma X_{ii} - \Sigma X_{i+}X_{+i} / M^2 - \Sigma X_{i+}X_{+i} \qquad \text{(Eq. 7)}$$

where
K_i = The conditional Kappa coefficient
M = The total number of observations
X_{ii} = The number of observations that agree for each class
+ = Summation over the index
X_{i+} = Marginal total of row i
X_{+i} = Marginal total of column i

The Kappa coefficient was found to be 97.52%. The significance testing results indicate that the classification is of acceptable accuracy.

B. *Individual Category Assessment*

The accuracy of individual land cover categories were also examined and include three different measures: producer's accuracy, user's accuracy, and the conditional Kappa coefficient. The producer's and user's accuracy measure errors of omission and commission, respectively. "Errors of omission refer to the samples of a certain class of the reference data that were not classified as such. Errors of commission refer to the samples of a certain class of the classified data that were wrongly classified" (Janssen and van der Wel, 1994). Conditional Kappa takes into account the estimated contribution of chance agreement for a specified category. The conditional Kappa coefficient can be measured for the reference data, which is similar to the producer's accuracy, or the classification data, which is similar to the user's accuracy.

Producer's accuracy is calculated by dividing the total number of correctly classified samples for a category (major diagonal) by the total number of reference samples for a given category. Thus, for water, the producer's accuracy is 100%, marsh 72.73%, meadow 96%, and upland 99.92%. User's accuracy is calculated by dividing the total number of correctly classified samples for a category by the total number of samples that were classified in that category. Thus, the user's accuracy for water is 98.62%, marsh 88.98%, meadow 99.31%, and upland 99.55%. The conditional Kappa coefficient is found by the equation (Fung and LeDrew, 1988):

$$K_u = MX_{ii} - X_{i+}X_{+i} / MX_{i+} - X_{i+}X_{+i} \qquad \text{(Eq. 8a)}$$
$$K_p = MX_{ii} - X_{i+}X_{+i} / MX_{+i} - X_{i+}X_{+i} \qquad \text{(Eq. 8b)}$$

where
K_u = Conditional Kappa related to user's accuracy
K_p = Conditional Kappa related to producer's accuracy

The conditional Kappa is 98.61% for water, 88.88% for marsh, 99.23% for meadow, and 95.95% for upland given the number of pixels classed as a given category, and is 100% for water, 72.71% for marsh, 95.97% for meadow, and 99.30% for upland for calculations related to producer's accuracy.

Although the accuracy assessment results of the classification were very high, the true accuracy is probably not this high. This will have to be kept in mind during the analysis of change between image classifications for different dates. As previously mentioned, there is some bias and error in the accuracy assessment procedure. However, judging by a visual comparison and a comparison of the spectral ranges used, most of the wetland areas were classified correctly. The change in the land surface will now be examined which will illustrate the nature and extent of wetland changes over time.

Chapter VII

CHANGE DETECTION METHODOLOGY

Two different change detection methods were applied to the Landsat MSS data of the study area. The first evaluates the spectral value data through regression analysis and indicates spectral/biophysical changes of the land surface. Image regression was found by Singh (1989) to perform better than simple image differencing and it is more statistically valid. The second method analyzes the classification data and indicates land cover changes. It has the ability to depict a variety of land cover changes that are meaningful to the analyst. If change is found to be significant by both image regression and post-classification comparison, then environmental changes of the land surface are revealed. But, if both types of changes do not occur, then the depicted changes may be due to classification error, the inability to correct for radiometric or geometric error, the limitations of the sensor in producing spectral separability of the desired features due to its low spectral and spatial resolution, or normal spectral change that occurs within a classification category.

A. *Spectral Change*

The first change detection indicator involves linear bivariate regression of the spectral values for several image date pairs which shows their relative association. "In the regression method of change detection, pixels from time t_1 are assumed to be a linear function of the time t_2 pixels" (Singh, 1989). The relative strength of the association is determined by the coefficient of determination (r^2), which is simply the ratio of the explained variation to the total variation in the dependent variable. The r^2 result indicates the percentage of variation in the dependent variable that is explained by the independent variable. Since the earlier year creates the effect, it is considered the independent variable, and the later year receives the influence so it is deemed the dependent variable. Residuals analysis will examine differences between the amount of variation that each wetland category explains and the spatial patterns of change. The null hypothesis states that there is no linear relationship between the independent variable (earlier date) and the dependent variable (later date). That is, it assumes that the prior year land surface does not influence the later year land surface.

The TVI coefficients of determination in Table V show that there is a moderate association between each image data pair, with r^2 values between 42% and 53%. The highest relationship is between 1973 and 1976 and the lowest relationship is from 1978 to 1984, although over the entire study period, from 1973 to 1991, the association was even lower. The regression values change only slightly when the adjusted r^2 values are used, which "attempt to correct r^2 to more closely reflect the goodness of fit of the model in the population" (SPSS, 1988).

The significance testing of the coefficient of determination shows that the earlier year values for each date pair account for a significant amount of the variation in the later year values (Table V). Therefore, the null hypothesis is rejected. However, there is still

Table V. TVI Regression Results

Year	Explained Variation	Unexplained Variation	Total Variation	Coefficient of Variation (r^2)	F-Value
1973/1976	114.67821	101.30846	215.98667	0.53095	149214.1264
1976/1977	102.74353	114.45601	217.19954	0.47304	118328.8366
1977/1978	165.00832	179.31567	344.32399	0.47922	121300.4248
1978/1984	123.77705	150.48036	274.25741	0.45132	108426.3919
1984/1991	133.11263	141.87574	274.98837	0.48407	123676.1134
1973/1991	116.74776	158.24061	274.98837	0.42456	97253.5202
Year	Significant-F	Standard Residuals: Minimum	Standard Residuals: Maximum	Slope (b)	Intercept (a)
1973/1976	0.0000	-16.2237	12.6449	0.790165	0.259447
1976/1977	0.0000	-14.7352	11.6731	0.689706	0.447743
1977/1978	0.0000	-17.6217	9.5100	0.871613	0.170945
1978/1984	0.0000	-18.9589	11.9160	0.599565	0.533939
1984/1991	0.0000	-22.8033	15.7450	0.696675	0.456036
1973/1991	0.0000	-23.0061	10.8271	0.797263	0.312456

considerable variation that is unexplained; a large amount of change is occurring in the land surface from one year to the next. Also, the F test assumes that a significant number of values must be over two standard deviations away from the mean in order to be significant. But this is an arbitrary threshold. The TVI values may have actually changed to a different land cover category spectral value at a Z-score of 1.0 or some other point.

In order to support the variation in spectral values and verify the rejection of the null hypothesis, the association between near-infrared values is examined. Later, residuals analysis will be examined to see what is causing the unexplained variation.

A sampling of the band 4 near-infrared spectral characteristics, using the 1978 reflectance image, was made for several wetland and upland areas. The results indicated that there was good spectral separability in the near-infrared for the three wetland categories, although there was some overlap between subirrigated meadow and upland values, as shown in Table VI. Since there was not strong TVI spectral separability, the examination of actual near-infrared spectral values lends support for the TVI analysis. The land cover areas in Table VI were determined by the classification images.

Table VI. Near-infrared Spectral Response over Different Land Cover Classes

Land Cover	Percent Reflectance
Water	1 - 8
Marsh	9 - 15
Meadow	16 - 42
Upland	28 - 53

Table VII illustrates that the association of near-infrared values between different years is slightly lower than the TVI values' comparison. But the ranking of the yearly comparisons remained the same, with 1973/1976 still having the highest relationship and 1978/1984 having the lowest. There was a relatively large decline (about 6%) in the association of band 4 values compared to the TVI values over the entire study period, with an r^2 value of only about 37%. The significance testing results show that the null hypothesis is again rejected for each year pair, indicating that there is a statistically significant relationship between the spectral values. However, there is still enough unexplained variation in the prior year data that cannot be explained by the later year data that the nature of the relationship needs to be examined further. This will be done through classification comparison and change image analysis.

Table VII. Near-infrared Regression Results

Year	Explained Variation	Unexplained Variation	Total Variation	Coefficient of Variation (r^2)	F-Value
1973/1976	617920.95688	643376.69903	1261297.65591	0.48991	126602.5096
1976/1977	677952.09467	792100.72750	1470052.82217	0.46118	112821.8749
1977/1978	748683.34576	865718.11046	1614401.45622	0.46375	113997.7784
1978/1984	780546.36198	1032700.12623	1813246.48821	0.43047	99632.0788
1984/1991	1022277.95237	1164675.99731	2186953.94968	0.46744	115701.3929
1973/1991	798690.19956	1388263.75012	2186953.94968	0.36521	75836.9904
Year	**Significant-F**	**Standard Residuals: Minimum**	**Standard Residuals: Maximum**	**Slope (b)**	**Intercept (a)**
1973/1976	0.0000	-8.9414	12.6630	0.620580	6.358240
1976/1977	0.0000	-10.9816	10.4653	0.733146	5.886594
1977/1978	0.0000	-9.3901	7.8430	0.713646	4.105323
1978/1984	0.0000	-8.4266	10.3916	0.699712	8.803652
1984/1991	0.0000	-9.1494	8.6512	0.750855	8.749804
1973/1991	0.0000	-10.0651	10.5415	0.705540	8.895510

B. *Post-Classification Comparison*

Post-classification comparison was performed using a cross-tabulation procedure to analyze changes in land cover classes from one image date to another. Six independently classified images were compared to each other. The results indicate the nature and extent of the land cover changes that have occurred both for individual classes and for all categories combined. The land cover change is examined both for the entire study site and for subsets of the study site. The latter analysis illustrates spatial variations of change. The null hypothesis states that there is no agreement between the land cover classifications for two different image dates. It will be tested by the Kappa coefficient of agreement.

1. *Entire Study Area*

a. All Categories

Two measures indicate the extent of agreement between the independently classified images: overall agreement and the Kappa coefficient of agreement. The overall agreement and Kappa are calculated in the same manner as their accuracy assessment equivalents. The overall agreement for each year pair is over 88%, as shown in Table VIII. All pairs are similar, ranging from 88.71% to about 92.5%. But, this measure is biased toward the category with the highest number of samples; in this case, the upland

Table VIII. Land Cover Agreement Between Dates

Year	Overall Agreement	Kappa Coefficient	T-Value (Kappa)	Significance
1973/1976	92.52	66.062	262.1737	.0000
1976/1977	92.52	60.027	244.4649	.0000
1977/1978	88.81	50.382	217.4434	.0000
1978/1984	88.71	57.375	236.9261	.0000
1984/1991	92.29	62.513	249.6634	.0000
Mean	90.97	59.27		
SD*	2.02	5.91		
1973/1991	90.99	59.265	235.6490	.0000

* Standard Deviation

class. Since the uplands are relatively stable compared to the wetlands, the overall agreement results do not vary much.

The Kappa coefficient is a more valid measure of the degree of change occurring between classifications. The Kappa values are lower, as shown in Table VIII, reflecting the influence of categories that have less agreement. The highest Kappa agreement is between 1973 and 1976 (65.27%) and the lowest is between 1977 and 1978 (50.38%). Thus, without the upland bias, the range of agreement is higher, being about 16% for the Kappa agreement and only about 4% for the overall agreement. It is interesting to note that one of the consecutive year pairs (1977/1978) does not have very high agreement, indicating that there may be considerable variation from one year to the next. Over the entire study period, shown in the comparison of 1973 to 1991, the agreement in land cover was about the same as the mean of each sequential year pair. The significance testing results show that the null hypothesis should be rejected; that is, there is statistically significant agreement between the land cover for all image comparisons.

b. Individual Category Change

The analysis of Kappa values illustrates that there is a considerable amount of variation in the land cover over time. Even though statistically there is significant agreement between image dates, the moderate Kappa values reveal that there is change occurring in the study area over time. In order to understand the nature of this variation, it is necessary to examine the individual category variation, which will help determine if the change in the entire study area is occurring mostly in one class, two or three classes, or evenly across all classes. In other words, is the variation in the land cover explained mostly by one class or a combination of classes?

Areal coverage was computed for each land cover class for each year (Table IX). Upland had the highest number of hectares, followed by subirrigated meadow. Marsh had the third highest hectares for all yearly comparison except 1977/1978, in which water had more areal coverage than marsh. But, generally, the number of hectares decreased as the land cover type increased in wetness: an inverse relationship existed between hectares and wetness of the land cover category.

Table IX. Land Cover Hectares for the Study Area

Land Cover	1973	1976	1977	1978	1984	1991
Water	530.4850	451.8484	458.7135	826.3084	453.7207	464.9545
Marsh	606.6252	564.1864	447.4797	743.3031	571.0515	590.3986
Meadow	9347.7698	8917.1408	6046.2808	12077.5832	7796.8813	8946.4735
Upland	71783.9820	72335.6864	75316.3880	68621.6673	73447.2085	72248.3124
Land Cover	1973/1976 Percent Change	1976/1977 Percent Change	1977/1978 Percent Change	1978/1984 Percent Change	1984/1991 Percent Change	1973/1991 Percent Change
Water	-14.82	1.52	80.14	-45.09	2.48	-12.35
Marsh	-7.00	-20.69	66.11	-23.17	3.39	-2.67
Meadow	-4.61	-32.19	99.75	-35.44	14.74	-4.29
Upland	0.77	4.12	-8.89	7.03	-1.63	0.65

The yearly comparison of land cover area change, shown in Table IX, reveals that most of the change occurred in the wetland classes; the uplands had less than 9% change for all image date comparisons. Some of the largest fluctuations occurred in the meadow class. However, for individual yearly comparisons, the wetland category with the highest change differed. The interrelationship of change also varied between different image date comparisons. Some comparisons, such as 1973 versus 1976, saw relatively little change across all wetland classes while others, such as 1977 to 1978 and 1978 to 1984, saw relatively high change across all classes, while still others had a high degree of change for one or two wetland classes but not for other classes. Over the study period, from 1973 to 1991, the wetlands decreased slightly for two wetland categories (marsh and meadow) and decreased relatively moderately for water.

Comparison between classes generally shows that uplands and wetlands are indirectly related to each other: an increase or decrease in upland is associated with a decrease or increase, respectively, in wetlands. Since uplands expand at the expense of wetlands, this relationship was to be expected. There appears to be a direct relationship among the three wetland classes, with only one yearly comparison (1976/1977) having one wetland class (water) increase while the other wetland classes decreased.

To further examine the change occurring in individual categories from one date to another, a persistence measure was used which "indicated the percent of each class that remained the same from the previous year" (Dinville, 1993). It is calculated in the same manner as the user's accuracy:

$$P = X_{ii} / X_{+i} \qquad \text{(Eq. 9)}$$

where
P = Percentage of a class that persisted from one date to another
X_{ii} = Number of pixels in common between two dates
X_{+i} = Earlier year total for a given class

Upland had the highest persistence for each yearly comparison, as shown in Table X, with over 90% of uplands in the earlier year still present in the later year and a mean persistence of about 96%. Water had the next highest persistence throughout with a mean of 70%, although the range of persistence was about was about 40%. Meadow had the third highest persistence overall with a mean of about 63% and marsh had the lowest persistence with a mean of about 39%. There were only two instances where a class with a higher overall mean persistence actually had a lower persistence for an individual yearly comparison: meadow was higher than water in the comparison of 1973 to 1976 and of 1978 to 1984. For the entire study period, 1973 to 1991, the persistence was relatively low for water, with only one year pair (1978/1984) having a lower value. But, for the other categories, the persistence of land cover from 1973 to 1991 was about the same as the mean for the other yearly comparisons. Thus, it cannot be ascertained by the persistence measure whether there are any long-term changes occurring in the wetlands.

Table X. Persistence of Land Cover Over Time

Year	Persistence: Water	Persistence: Marsh	Persistence: Meadow	Persistence: Upland
1973/1976	63.4	44.5	66.6	96.5
1976/1977	72.4	38.1	51.2	98.2
1977/1978	89.7	29.6	77.7	90.1
1978/1984	48.6	27.5	49.1	98.0
1984/1991	77.6	55.0	68.4	95.2
Mean	70.3	38.9	62.6	95.6
SD*	15.4	11.3	12.1	3.3
1973/1991	60.6	38.4	60.2	95.7

* Standard Deviation

Some general relationships were found in the persistence values. The wetland classes have a direct relationship to each other and the uplands have an indirect relationship with the wetlands. These relationships were the same as the hectare relationships.

2. *Subsets: Spatial Analysis*

The study area was divided into nine subsets in order to determine if the changes in the land cover classes varied spatially over time. If differences were found between subsets, then the nature of the landscape may explain the variation. The null hypothesis states that there is no significant difference in agreement for each yearly comparison of the nine subsets. It is tested by the Kappa coefficient.

The overall agreement for each subset is relatively high, with a mean agreement ranging from 87.78% for subset 8 to 95.23% for subset 3 (Table XI). The more reliable Kappa coefficient ranges from 46.27% for subset 3 to 63.84 for subset 8. The significance testing results show that the null hypothesis should be rejected; there is statistically significant agreement between the land cover classifications for each subset's yearly comparison.

The Kappa values for each yearly comparison were ranked in order to better understand the variation between subsets over time (Figure 10). Although subsets 3 and 8 were consistently low and high, respectively, in ranking across all yearly comparisons, other subsets showed more variation. For example, subset 5 had high agreement for some comparisons, but low agreement for others. Insight into the causes and nature of the spatial variation in agreement may be gained by an examination of individual class changes among the subsets.

Table XI. Land Cover Agreement for Subsets: Summary Statistics

Statistic & Subset #	Overall Agreement	Kappa
Mean 1	91.48	61.22
SD	2.00	8.84
Mean 2	93.84	50.07
SD	1.13	5.33
Mean 3	95.23	46.27
SD	1.20	7.08
Mean 4	90.77	61.51
SD	1.31	6.46
Mean 5	91.39	57.56
SD	1.90	11.00
Mean 6	89.30	55.32
SD	3.05	10.60
Mean 7	88.08	57.65
SD	2.82	4.92
Mean 8	87.78	63.84
SD	1.67	4.56
Mean 9	92.65	57.64
SD	2.08	8.99

spatial variation in agreement may be gained by an examination of individual class changes among the subsets.

For individual categories, an areal comparison across the nine subsets revealed that uplands maintained the highest hectares throughout all yearly comparisons, while meadows maintained the second highest. Depending upon the classification date comparison and the subset, marsh or water had the lowest number of hectares. The

Figure 10. Diagram of Kappa Results for Subsets

	Kappa	Rank	Kappa	Rank	Kappa	Rank
1973/1976	63.40	6	69.80	2	56.90	7
1976/1977	59.51	6	60.47	3	59.88	4
1977/1978	47.35	5	52.20	3	50.35	4
1978/1984	64.58	3	64.61	2	57.35	4
1984/1991	71.28	1	60.47	5	63.79	4
Average	61.22	3	61.51	2	57.65	4
1973/1991	58.68	4	58.25	5	50.49	7
1973/1976	51.96	9	73.32	1	68.31	4
1976/1977	49.09	8	64.29	1	60.77	2
1977/1978	41.24	8	53.69	2	57.46	1
1978/1984	54.00	5	47.20	7	65.63	1
1984/1991	54.05	7	49.29	9	67.01	2
Average	50.07	8	57.56	6	63.84	1
1973/1991	36.35	9	64.48	3	65.08	2
1973/1976	54.79	8	68.88	3	66.27	5
1976/1977	46.93	9	59.58	5	58.93	7
1977/1978	38.23	9	43.60	7	45.51	6
1978/1984	40.13	9	45.52	8	51.76	6
1984/1991	51.28	8	59.01	6	65.72	3
Average	46.27	9	55.32	7	57.64	5
1973/1991	48.36	8	65.12	1	56.78	6

Legend

Subset #		
1	4	7
2	5	8
3	6	9

summary statistics for hectares in Table XII show that there is considerable variation in the mean number of hectares for each subset's classes. For example, subset 8 has the largest meadow hectares coverage with a mean of about 1675 for all image date comparisons, and relatively small upland hectare coverage. On the other hand, subset 3 has the smallest mean meadow area, with a mean of about 370, but the largest upland area. The percentage change in hectares among the subsets was heavily influenced by small areas of water having relatively large change, although absolute growth or decline was very little for these areas. As opposed to the entire study area areal comparison, the direct relationship between all wetland classes was not always present. There were three instances where one wetland class decreased while the other two increased.

Persistence was also examined for each subset, with summary results contained in Table XIII. Water has the greatest range of mean persistence values among the subsets, ranging from 14% to 88%, while upland has the lowest, with a range from 93% to 98%. Subset 1 has the highest mean persistence for water and meadow, while subset 3 has relatively low persistence for each wetland category. The relationship of wetlands to uplands for the persistence measure is not as strong as the relationships that were seen for the agreement and hectare measures. However, subset 2 did have the lowest mean wetland persistence and the second highest upland persistence.

In order to more fully understand the relationships between the subsets, an overlay was created illustrating the statistical ranking of each subset for each statistical measure, as shown in Figure 11. The results indicate that larger wetland areas had the highest

Table XII. Land Cover Hectares for Subsets: Summary Statistics

Hectares and Subset #	Mean Hectares	Mean Change	SD Hectares
Water 1	136.26	2.88	11.78
Marsh	48.47	18.68	20.69
Meadow	935.01	18.71	244.19
Upland	8048.29	-0.38	262.88
Water 2	28.81	631.54	20.58
Marsh	31.21	6.19	19.67
Meadow	530.74	35.27	194.51
Upland	8577.32	-0.10	198.62
Water 3	20.08	62.04	16.22
Marsh	39.01	-7.18	13.40
Meadow	371.55	28.12	152.58
Upland	8737.40	0.37	156.47
Water 4	39.63	30.50	17.10
Marsh	80.40	13.91	30.33
Meadow	1166.44	1.55	225.03
Upland	7881.55	0.98	263.14
Water 5	29.12	50.90	17.25
Marsh	85.29	-0.12	16.67
Meadow	958.72	7.58	257.84
Upland	8094.89	0.81	282.63
Water 6	123.57	0.37	51.80
Marsh	139.90	13.67	28.70
Meadow	976.09	20.06	292.89
Upland	7928.46	0.25	336.51
Water 7	2.39	66.67	1.65
Marsh	11.34	30.66	4.09
Meadow	1487.33	12.39	420.06
Upland	7585.83	-0.08	424.04
Water 8	122.53	10.52	35.69
Marsh	93.41	14.62	25.01
Meadow	1673.73	-1.18	271.19
Upland	6353.75	56.07	2190.86
Water 9	28.60	17.45	15.49
Marsh	61.27	22.11	20.42
Meadow	755.79	11.05	162.66
Upland	8241.24	-0.13	193.77

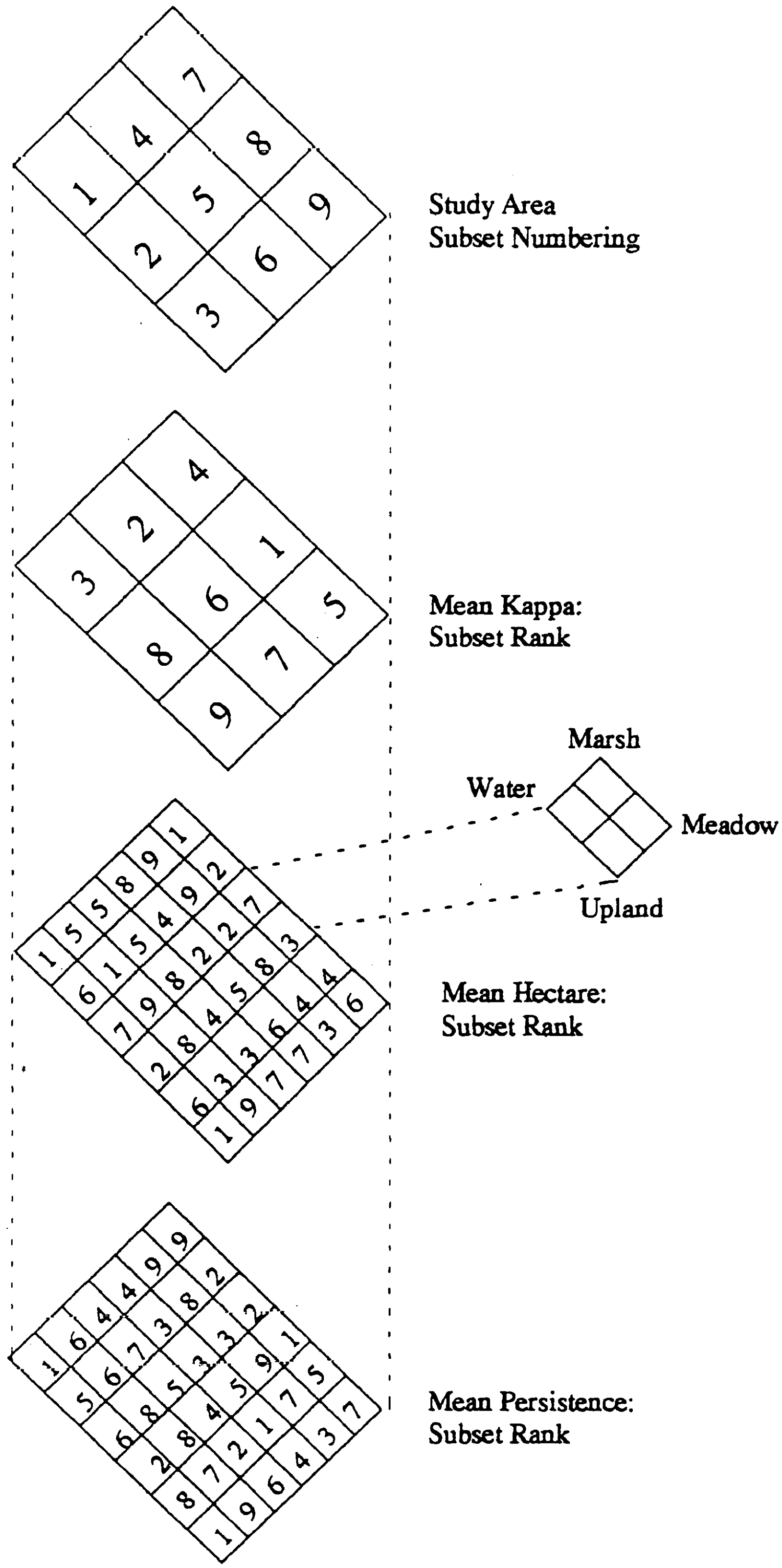
Table XIII. Persistence of Land Cover for Subsets: Summary Statistics*

Statistic and Subset #	Persistence: Water (%)	Persistence: Marsh (%)	Persistence: Meadow (%)	Persistence: Upland (%)
Mean 1	88.70	40.40	69.80	95.30
SD*	5.18	17.94	13.20	3.69
Mean 2	48.76	24.30	56.80	96.86
SD	35.56	17.10	19.99	2.41
Mean 3	53.50	45.72	47.88	97.84
SD	34.19	19.58	20.22	1.79
Mean 4	57.26	31.92	64.44	95.70
SD	22.07	10.20	8.22	3.43
Mean 5	42.42	48.14	60.48	96.04
SD	35.09	12.86	16.20	3.32
Mean 6	64.64	40.18	57.34	95.04
SD	23.50	16.89	18.12	4.59
Mean 7	14.44	53.16	67.56	92.84
SD	22.08	12.55	14.68	5.44
Mean 8	75.82	32.80	67.50	93.84
SD	16.72	12.66	7.93	4.16
Mean 9	60.98	40.90	59.92	93.36
SD	25.12	12.14	11.77	2.53

* Excludes 1973/1991 comparison; SD = Standard Deviation.

agreement over time. For example, subset 8 had the highest ranking of mean wetland hectares and also had the highest Kappa across all image date comparisons. The reverse is true for smaller wetland areas: subset 3 had the lowest overall ranking of wetland hectares and also had the lowest Kappa mean. High mean hectare ranking for a subset also tended to relate directly to high persistence for a particular land cover class. Thus, large wetland areas are more stable. However, there are exceptions to these associations. For example, subset 7 has the highest mean persistence rank for the marsh category, but the lowest marsh hectare ranking. Therefore, the nature of the wetlands and the processes at work

Figure 11: Overlay of Subset Summary Statistics



are too intricate for the statistical analysis to reveal. Further understanding will now be attempted by the examination of change images, both for spectral and classification data.

C. *Change Image Analysis*

1. *Spectral/Residuals Change Image Analysis*

The residuals from the regression procedure for both TVI and near-infrared data were examined in order to gain insight into where and why the unexplained variation occurred. That is, it is examined whether there are unique spatial patterns and/or land cover changes associated with underprediction (positive residuals) and overprediction (negative residuals). Positive residuals result when the TVI and near-infrared (NIR) values for the earlier date image data are lower than the later date image values—such as when plant biomass is higher for the later year—causing the regression equation to underpredict the later year values. Negative residuals result when the TVI and NIR values are lower for the later date image than for the earlier date image. Residual images using the slope and intercept values from the regression analysis were produced using the following equation:

$$\text{Residual} = Y - Y_p = Y - (a + bX) \qquad \text{(Eq. 10)}$$

where
Y = Actual value of the dependent variable (later year)
Y_p = Predicted regression line value of Y
a = Y-intercept
b = Slope
X = Value of the independent variable (earlier year)

The resultant image illustrates the magnitude and direction of the error in predicting the later date spectral values. These images are shown in Figures 12 through 23, with dark areas representing positive residuals—higher TVI and NIR values for the later date image—and light areas indicating negative values - lower values for the later date image.

In order to better highlight the negative residuals and the positive residuals, individual images were produced for both the positive and negative residuals and then were enhanced using a histogram stretch. The darkest areas indicate "significant" spectral change; that is, the TVI and NIR values are the farthest away from the prediction line. "Moderate" change is shown as gray areas. These images, shown in Figures 24 to 35, contain only the TVI regression results, since there seemed to be a strong relationship between the TVI and near-infrared residuals. However, all results were compared to the near-infrared residual images to ensure validity of conclusions. Each image date comparison will be examined briefly and later overall evaluations will be made after the classification change image comparison.

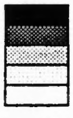
The residual images for 1973 and 1976 indicate moderate positive residuals in most subirrigated meadows, especially for the TVI values, meaning that the TVI values were higher in meadows in 1976 than in 1973. Two smaller marshes had "significantly" higher than predicted TVI values. There were moderately lower TVI and NIR values in 1976 for uplands and several marsh areas. Swan Lake and Brown Lake had significantly lower TVI values in 1976 than in 1973.

Figure 12. TVI Residuals Image: 1973 versus 1976

Scale
1 : 233440.43

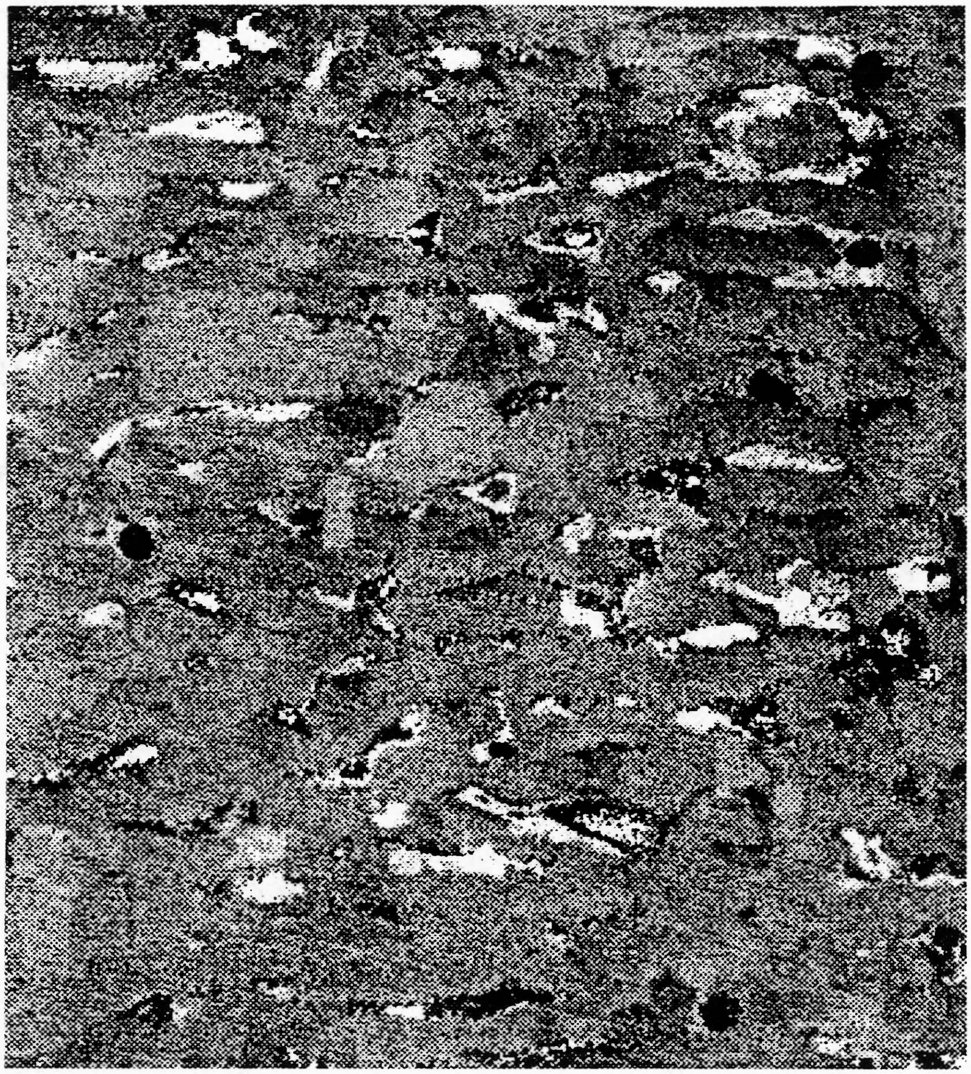
Legend

Residual



Strongly Positive
No Significant Change
Strongly Negative

Figure 13. TVI Residuals Image: 1976 versus 1977



Scale
1 : 233440.43

Legend

Residual

Strongly Positive
No Significant Change
Strongly Negative

Figure 14. TVI Residuals Image: 1977 versus 1978

Scale
1 : 233440.43

Legend

Residual

Strongly Positive
No Significant Change
Strongly Negative

Figure 15. TVI Residuals Image: 1978 versus 1984

Scale
1 : 233440.43

Legend

Residual

Strongly Positive
No Significant Change
Strongly Negative

Figure 16. TVI Residuals Image: 1984 versus 1991

Scale
1 : 233440.43

Legend

Residual

Strongly Positive
No Significant Change
Strongly Negative

Figure 17. TVI Residuals Image: 1973 versus 1991

Scale
1 : 233440.43

Legend

Residual

Strongly Positive
No Significant Change
Strongly Negative

Figure 18. Near-infrared Residuals Image: 1973 versus 1976

Scale
1 : 233440.43

Legend

Residual

Strongly Positive
No Significant Change
Strongly Negative

Figure 19. Near-infrared Residuals Image: 1976 versus 1977

Scale
1 : 233440.43

Legend

Residual

Strongly Positive
No Significant Change
Strongly Negative

Figure 20. Near-infrared Residuals Image: 1977 versus 1978

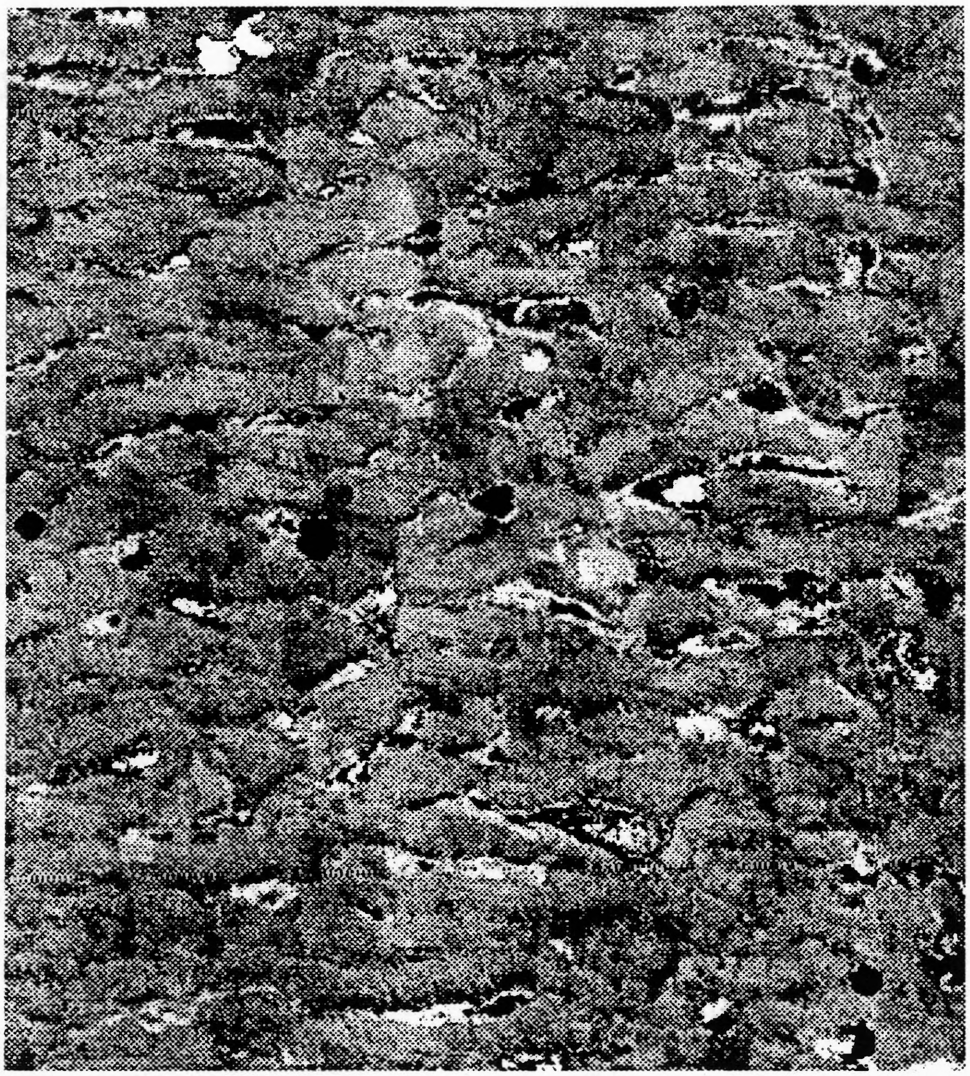
Scale
1 : 233440.43

Legend

Residual

Strongly Positive
No Significant Change
Strongly Negative

Figure 21. Near-infrared Residuals Image: 1978 versus 1984



Scale
1 : 233440.43

Legend

Residual

Strongly Positive
No Significant Change
Strongly Negative

Figure 22. Near-infrared Residuals Image: 1984 versus 1991

Scale
1 : 233440.43

Legend

Residual

Strongly Positive
No Significant Change
Strongly Negative

Figure 23. Near-infrared Residuals Image: 1973 versus 1991

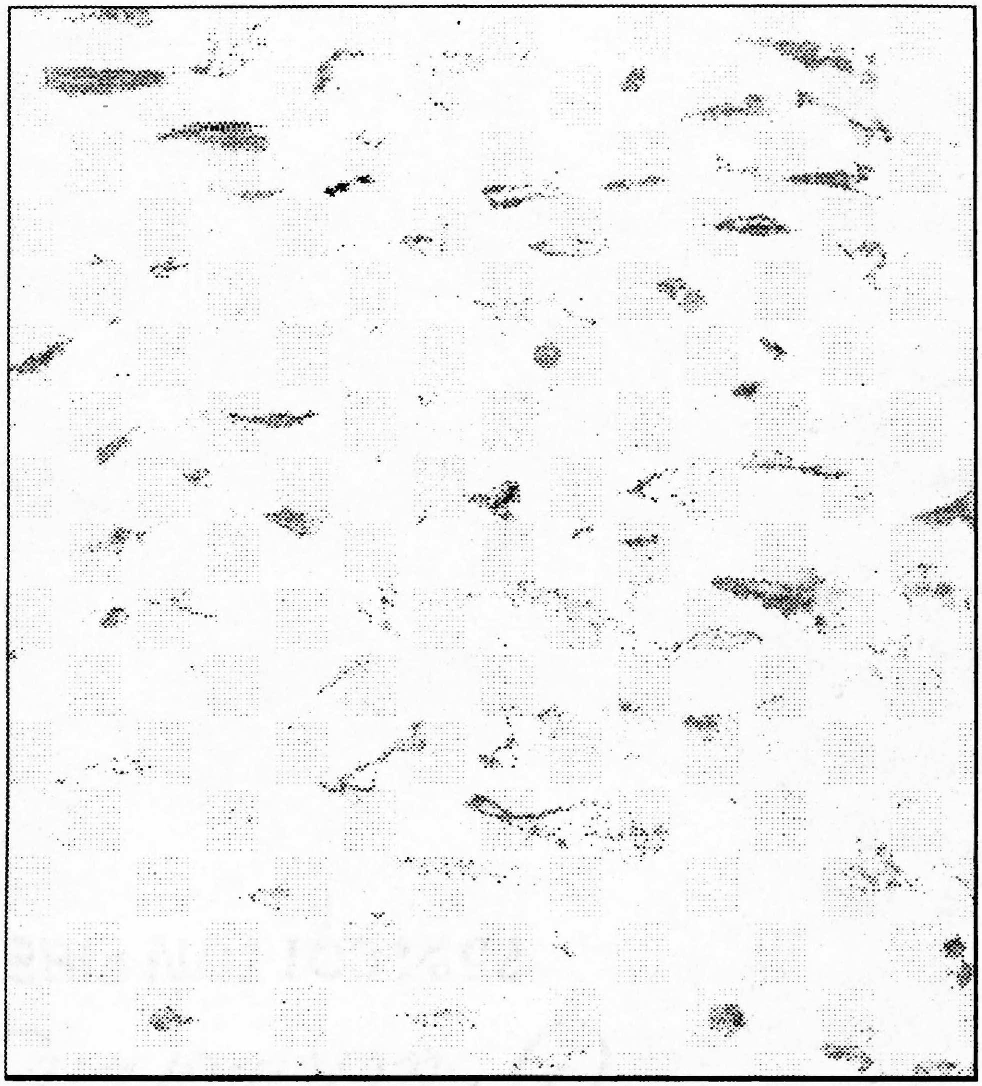
Scale
1 : 233440.43

Legend

Residual

Strongly Positive
No Significant Change
Strongly Negative

Figure 24. TVI Positive Residuals Image: 1973 versus 1976



Scale
1 : 233440.43

Legend

Residual

Strongly Positive
Moderately Positive
No Change

Figure 25. TVI Negative Residuals Image: 1973 versus 1976

Scale
1 : 233440.43

Legend

Residual

Strongly Negative
Moderately Negative
No Change

Figure 26. TVI Positive Residuals Image: 1976 versus 1977

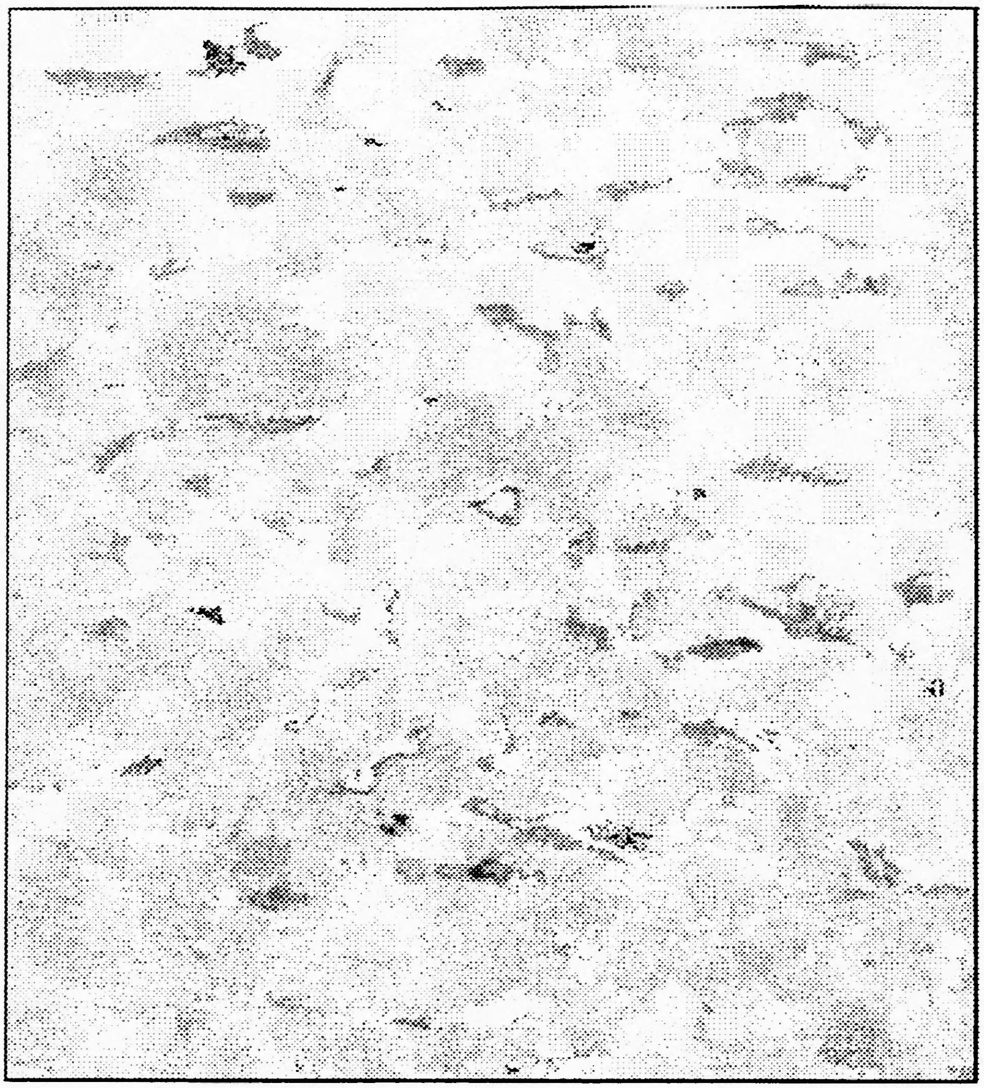
Scale
1 : 233440.43

Legend

Residual

Strongly Positive
Moderately Positive
No Change

Figure 27. TVI Negative Residuals Image: 1976 versus 1977



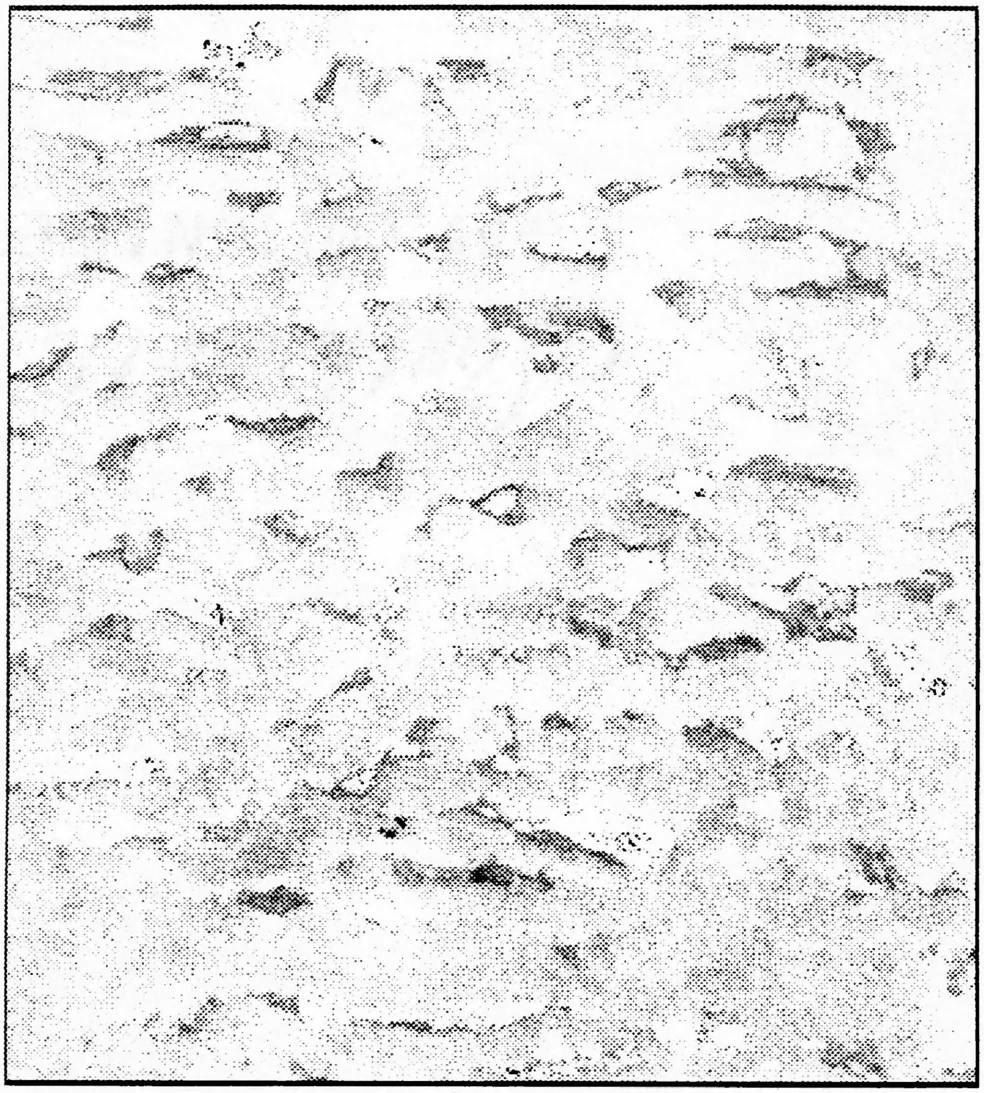
Scale
1 : 233440.43

Legend

Residual

Strongly Negative
Moderately Negative
No Change

Figure 28. TVI Positive Residuals Image: 1977 versus 1978



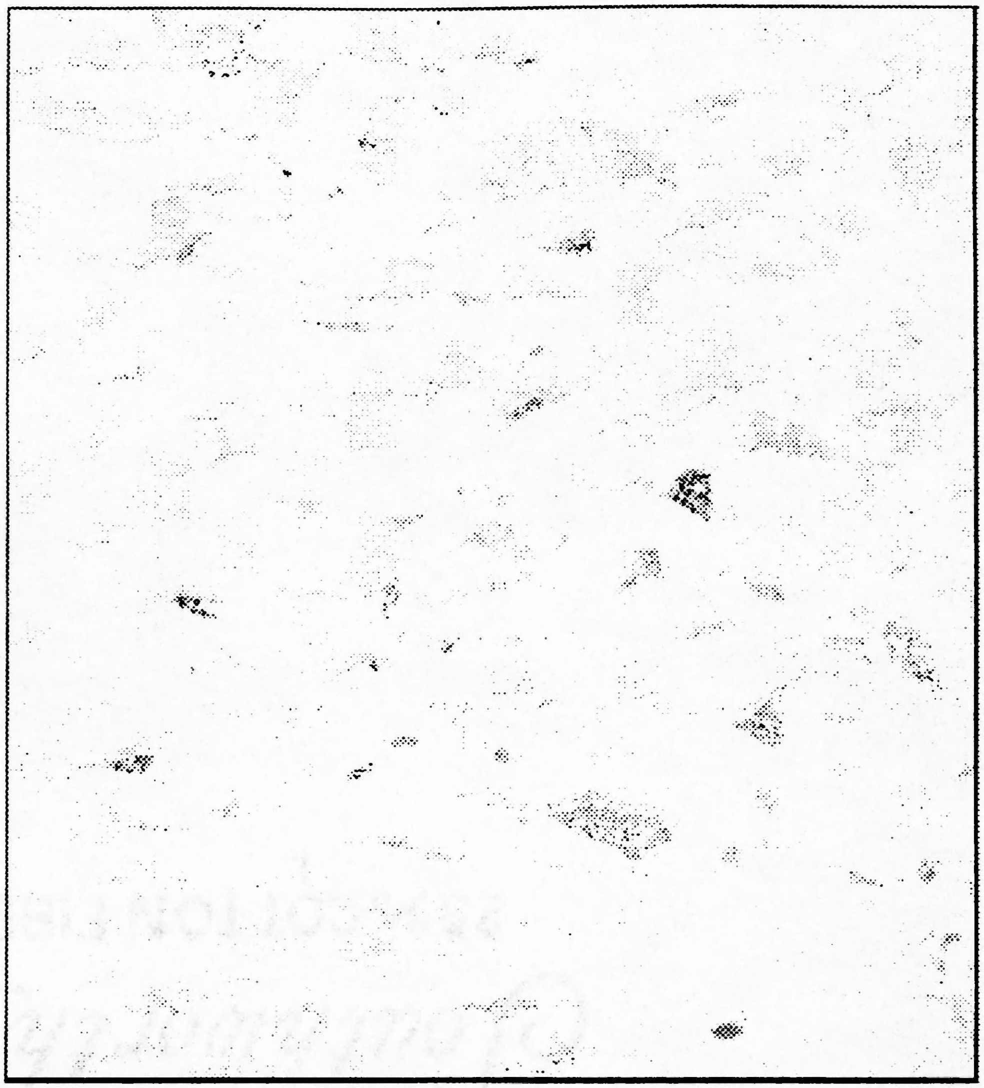
Scale
1 : 233440.43

Legend

Residual

Strongly Positive
Moderately Positive
No Change

Figure 29. TVI Negative Residuals Image: 1977 versus 1978



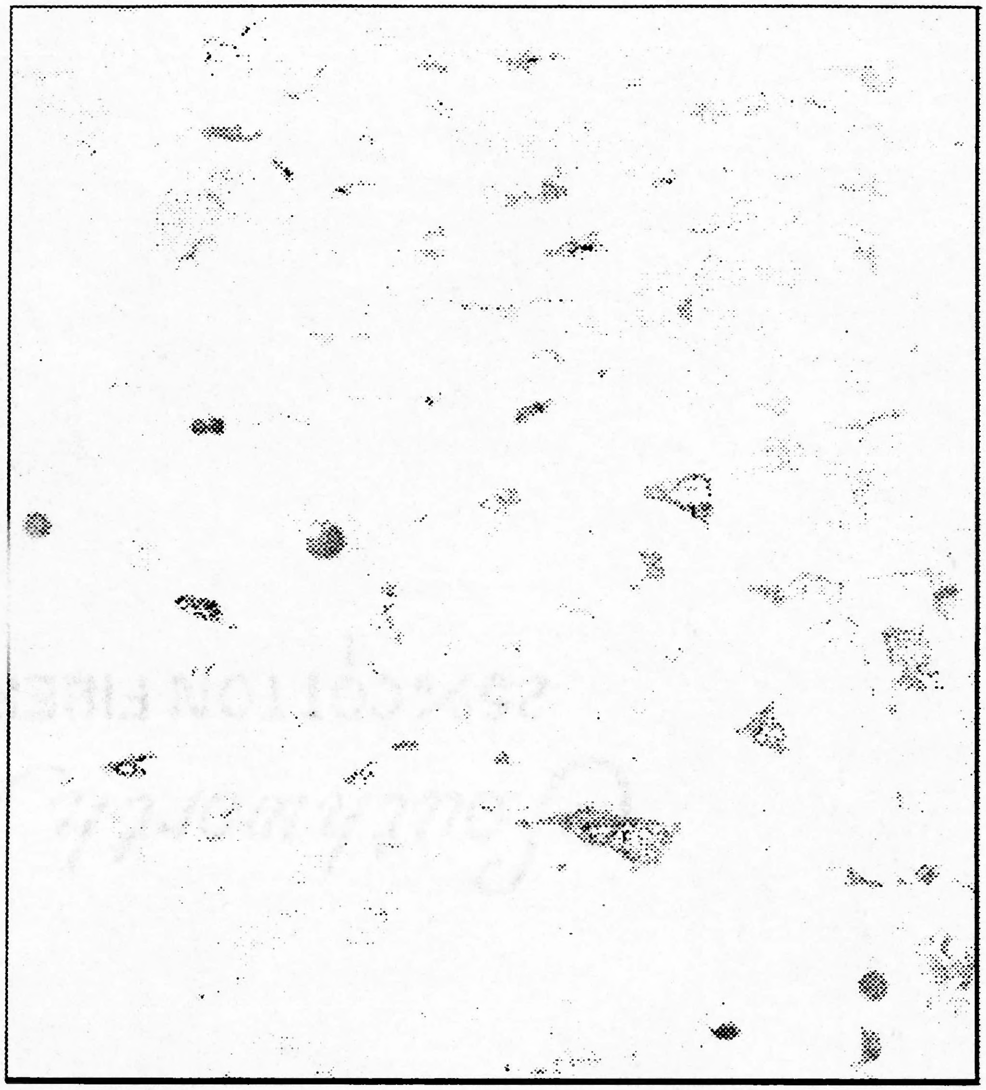
Scale
1 : 233440.43

Legend

Residual

Strongly Negative
Moderately Negative
No Change

Figure 30. TVI Positive Residuals Image: 1978 versus 1984



Scale
1 : 233440.43

Legend

Residual

Strongly Positive
Moderately Positive
No Change

Figure 31. TVI Negative Residuals Image: 1978 versus 1984

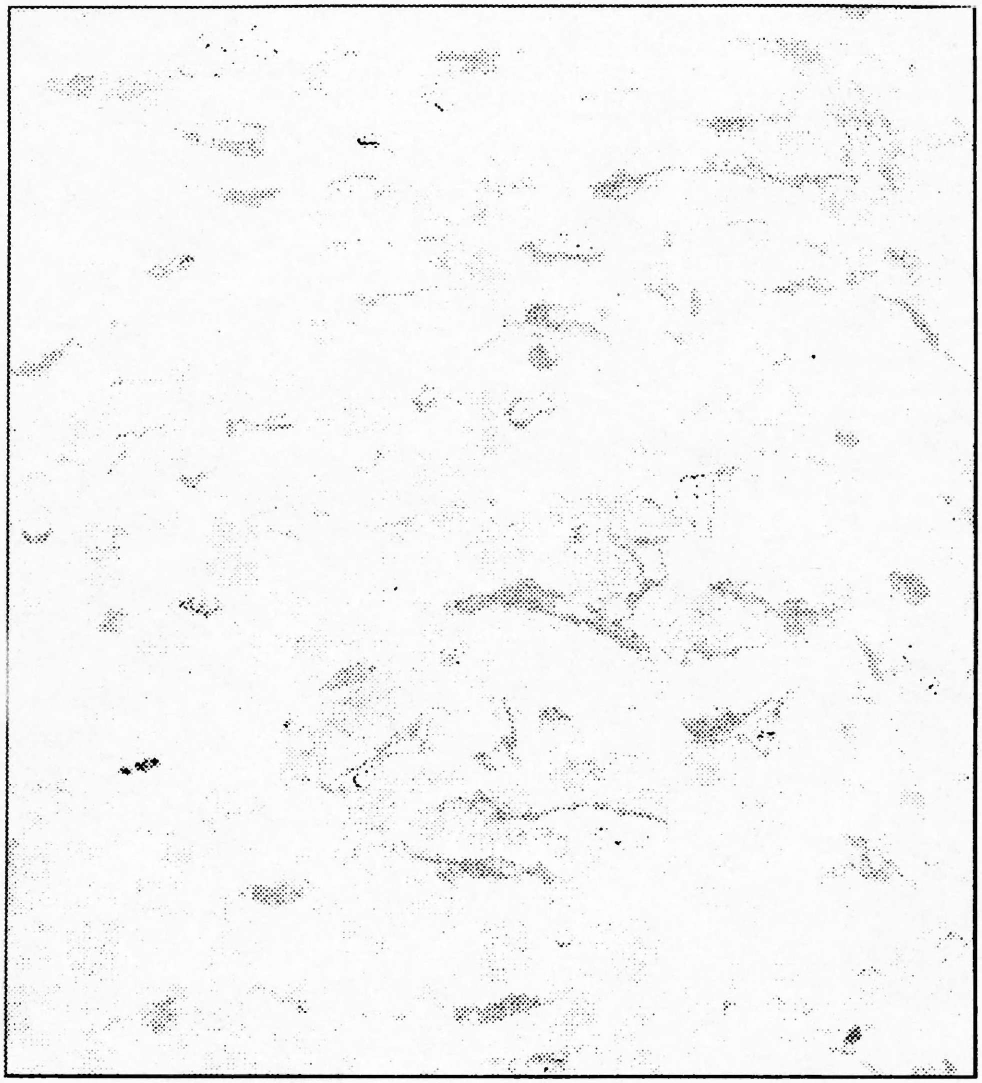
Scale
1 : 233440.43

Legend

Residual

Strongly Negative
Moderately Negative
No Change

Figure 32. TVI Positive Residuals Image: 1984 versus 1991



Scale
1 : 233440.43

Legend

Residual

Strongly Positive
Moderately Positive
No Change

Figure 33. TVI Negative Residuals Image: 1984 versus 1991

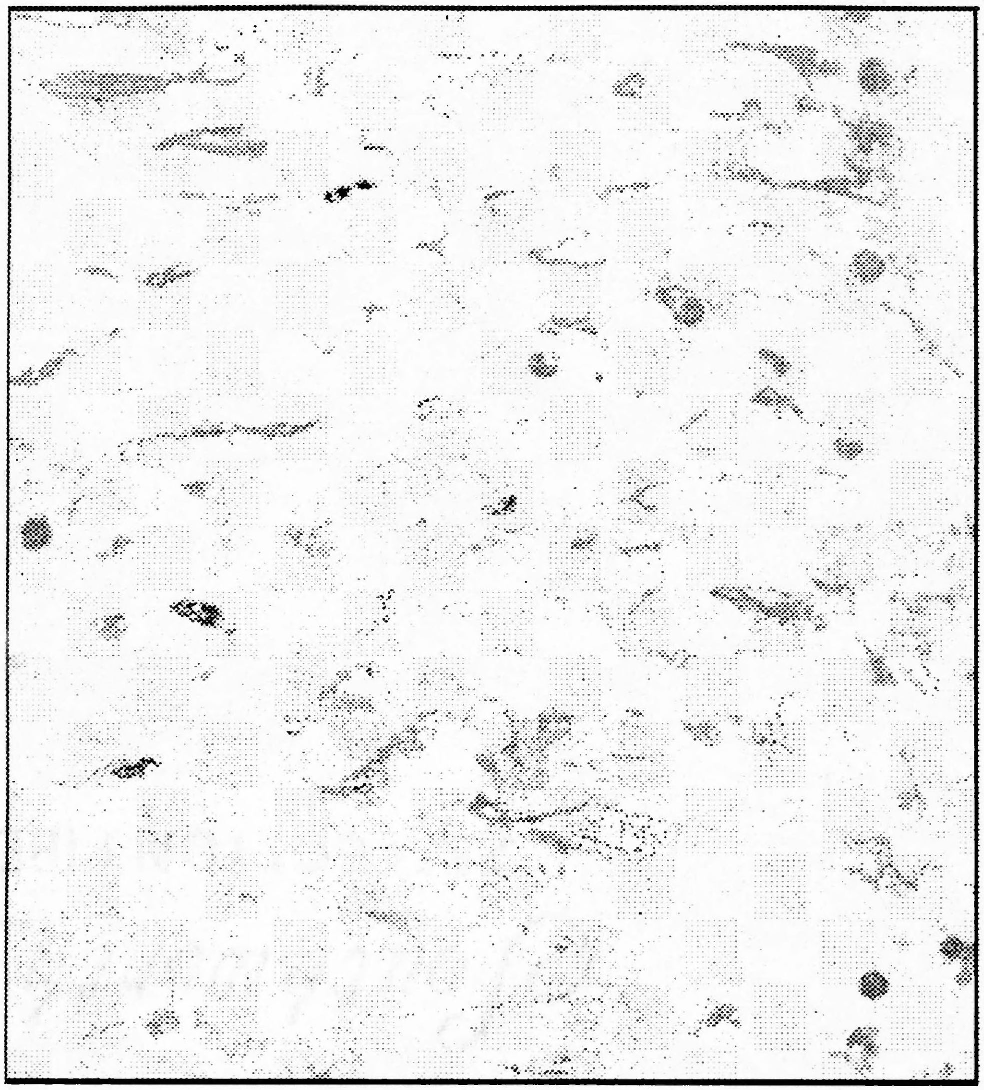
Scale
1 : 233440.43

Legend

Residual

Strongly Negative
Moderately Negative
No Change

Figure 34. TVI Positive Residuals Image: 1973 versus 1991



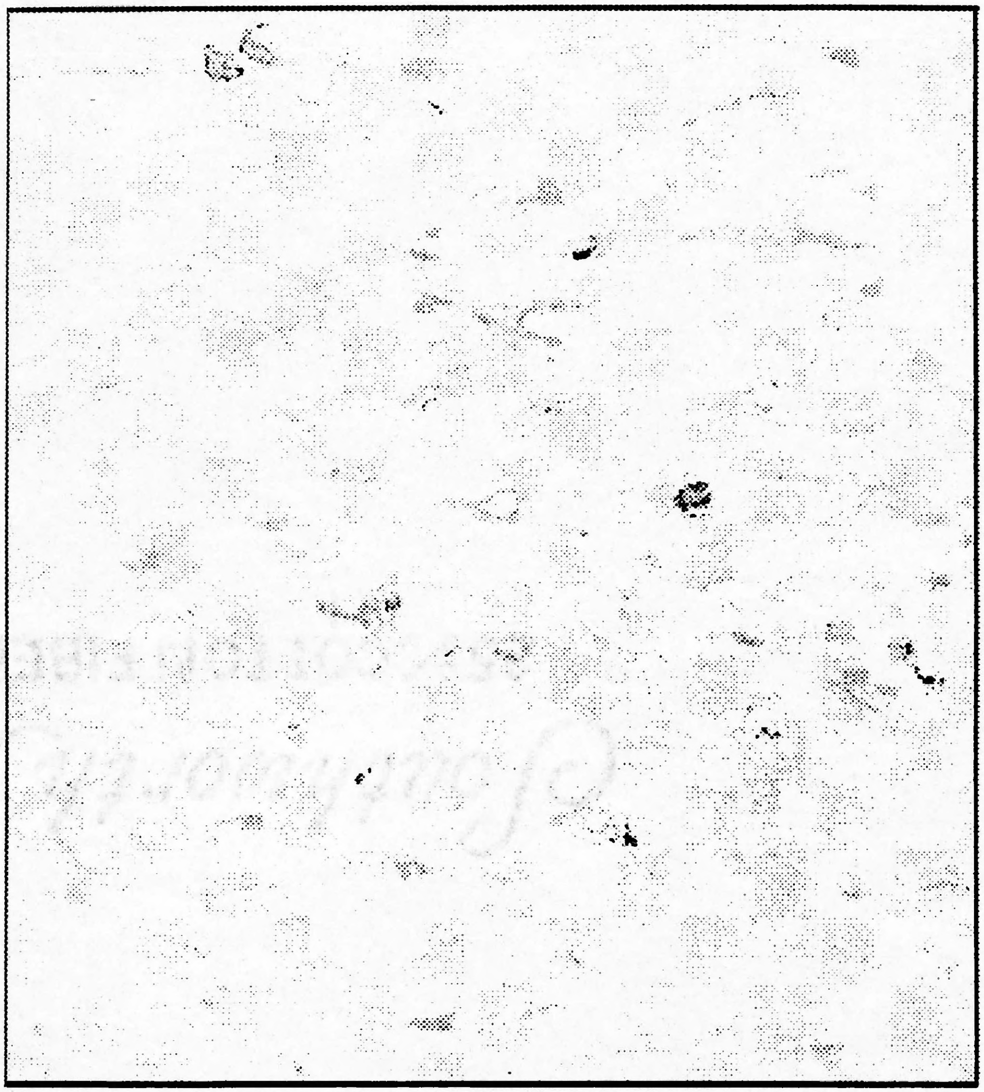
Scale
1 : 233440.43

Legend

Residual

Strongly Positive
Moderately Positive
No Change

Figure 35. TVI Negative Residuals Image: 1973 versus 1991



Scale
1 : 233440.43

Legend

Residual

Strongly Negative
Moderately Negative
No Change

The comparison of 1976 to 1977 shows that center pivot irrigation in 1977 caused the TVI values to be higher in 1977 in these areas. The TVI values were also significantly higher around the edges of Swan Lake and, for the near-infrared data, for several small marshes. The negative residuals images show that 1977 had moderate to very low TVI values in meadow areas compared to 1976. Thus, it is interesting to note that some meadow areas had moderately low negative residuals while other areas had moderately high positive residuals, which shows spatial variation of change.

Compared to 1977, the TVI values in most meadows were higher in 1978. Many upland areas had moderately higher than predicted TVI values in 1978. Several marshes had small areas where the TVI values were significantly higher in 1978, although other parts of some of these same marshes had significantly lower TVI values in 1978. There did appear to be more marsh/meadow changes in the negative residuals images while positive residuals images showed more highly significant changes in the water/marsh areas.

Spring Valley, Swan Lake, and K.C. Lake had moderately lower TVI values in 1984 than in 1978, as did parts of some small wetlands. Sand Puddin' Lake and some center pivot irrigation areas had higher TVI values in 1984 as did the marsh/meadow interface. The meadow/upland transition had higher TVI values in 1978 as did most of the uplands.

The 1984 and 1991 residual images show moderately higher than predicted TVI values for most meadows while some center pivot irrigation in 1984 caused the TVI values to be higher than predicted in certain areas in 1984 than in 1991. Parts of Sand

Puddin' and K.C. Lake had higher TVI values in 1991, but other lakes and some small marshes had lower than predicted TVI values in 1991, with the lowest values along marsh edges.

The change in spectral response over the entire study period is shown in Figures 34 and 35, which illustrates change between 1973 and 1991. Several meadow areas and areas that had center pivot irrigation in 1991 had higher TVI values in 1991 than in 1973. Sand Puddin' Lake, K.C. Lake, and a couple of other wetlands had moderate to significantly higher TVI values in 1991. Several other lakes, such as Spring Valley, Swan, and parts of Threemile, had moderate to significantly lower TVI values, as did some small marshes and some small meadow areas.

In summary, the analysis of the positive and negative residuals images illustrates that there is significant spectral variation occurring in the study area over time. The greatest magnitude of change, indicated by very high or very low residuals, occurs in water and marsh areas. They also had the highest spatial variation; that is, some lakes and marshes may have TVI and NIR values that were very much higher than predicted for the later year while at the same time other lakes and marshes may have significantly lower TVI and NIR values for the later year.

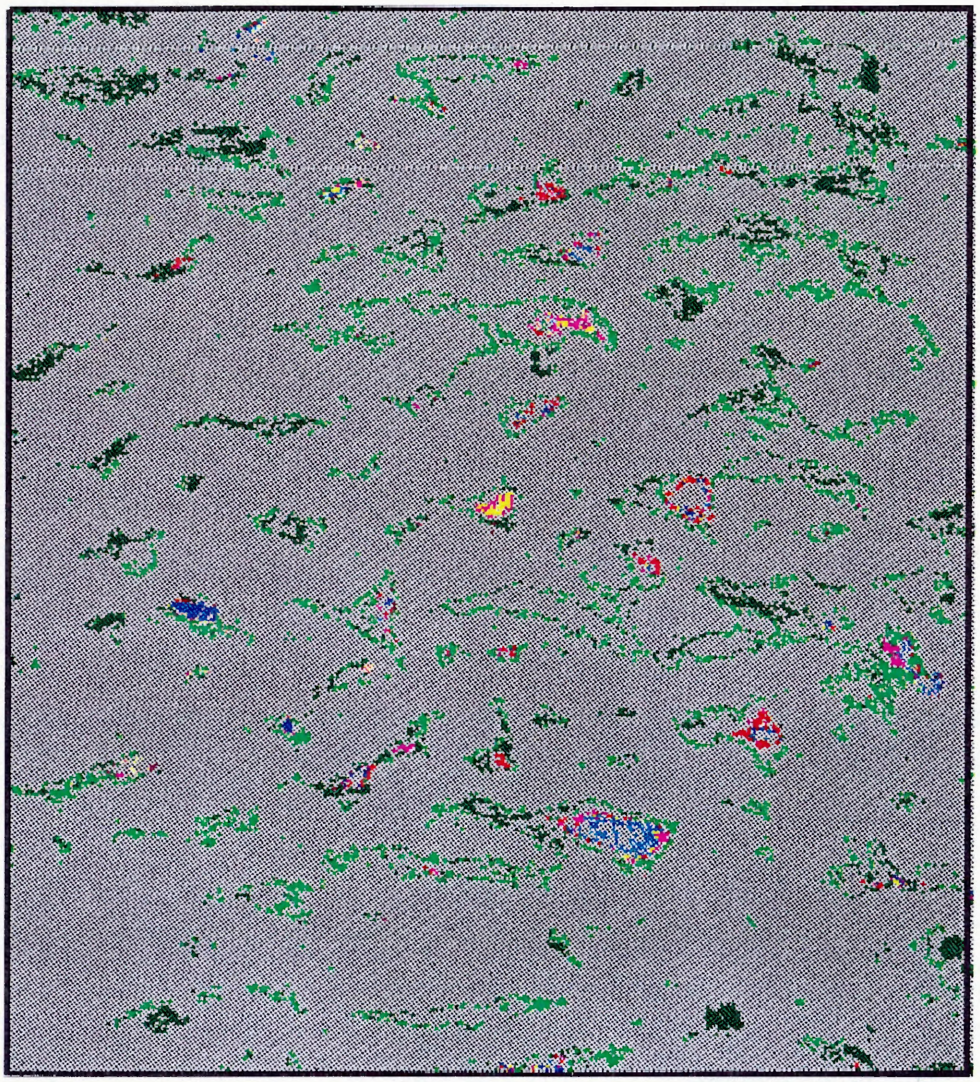
Subirrigated meadows tended to have more consistent change over space than lakes and marshes. The outer edges of meadows usually had greater change in spectral response than did the central portions. Center pivot irrigation had a larger impact on meadow changes than this study originally assumed they would. For example, 1984 had about four center pivot areas that produced high biomass late in the growing season (August) while at the same time traditional meadow areas had relatively low TVI values due to plant senescence and/or hay mowing. Since center pivot irrigated areas are usually spectrally classed as meadows, these areas actually had moderately higher TVI and NIR values in 1984 than in 1978, even though overall 1978 had over 4250 more hectares of meadow (per classification data).

Classification comparison changes will now be analyzed to show the land cover relationships between different years. Afterward, a final analysis will contrast and compare spectral and land cover changes.

2. *Land Cover Change Image Analysis*

Classification change images were also produced in order to further analyze the spatial and temporal change occurring in the wetlands and to gain insight into the processes responsible. The classified image values from time 2 (t_2) were subtracted from the classified image values from time 1 (t_1) to create a difference image. The resultant values were coded to represent the type of land cover change that had occurred, such as water to marsh, as shown in Plates 13 through 18. This will graphically illustrate the spatial change indicated in the statistical analysis of the subsets. Each date comparison will be examined individually and then an overall analysis will be made in conjunction with the residuals image analysis.

Plate 13. Change in Land Cover Classification from 1973 to 1976



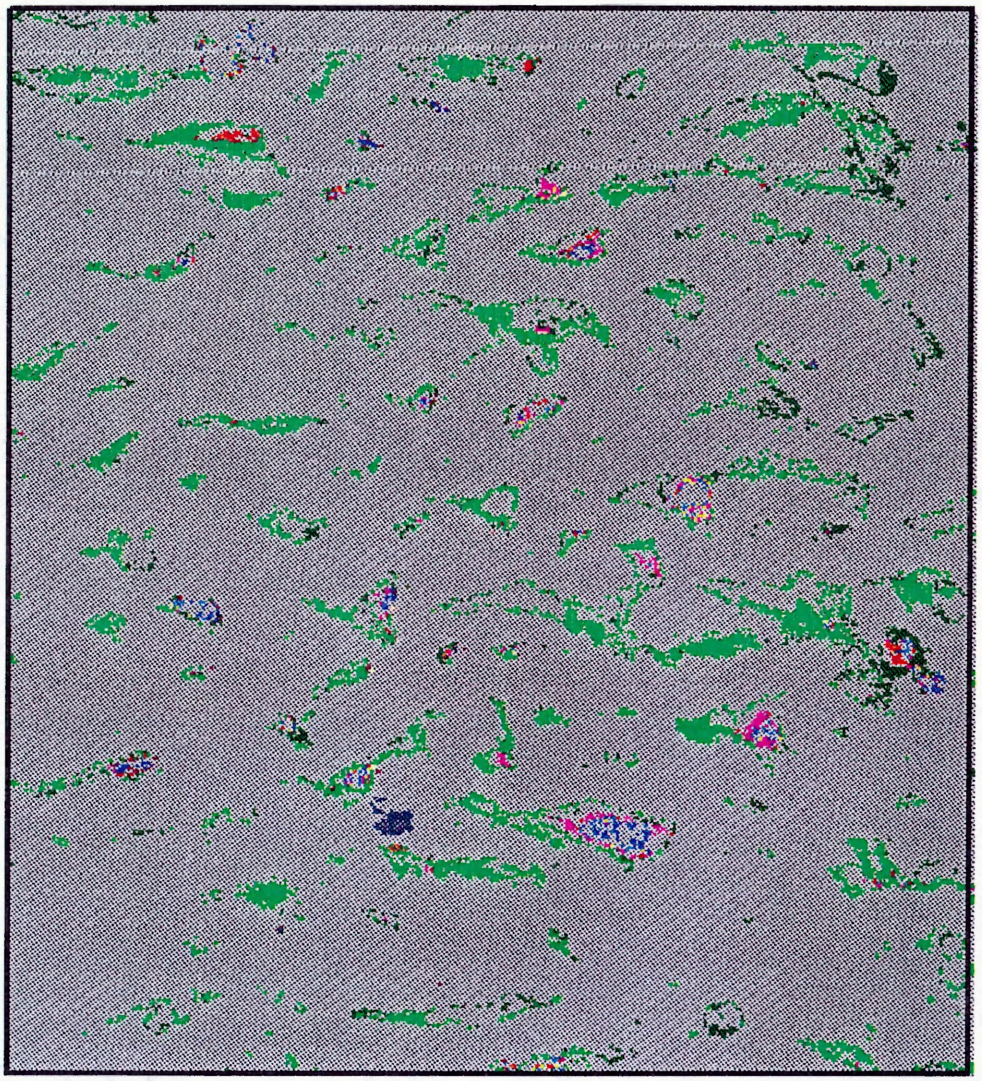
Scale
1 : 233440.43

Legend

- Upland to Water
- Upland to Marsh
- Meadow to Water
- Upland to Meadow
- Meadow to Marsh
- Marsh to Water
- No change
- Water to Marsh
- Marsh to Meadow
- Meadow to Upland
- Water to Meadow
- Marsh to Upland
- Water to Upland

N

Plate 14. Change in Land Cover Classification from 1976 to 1977



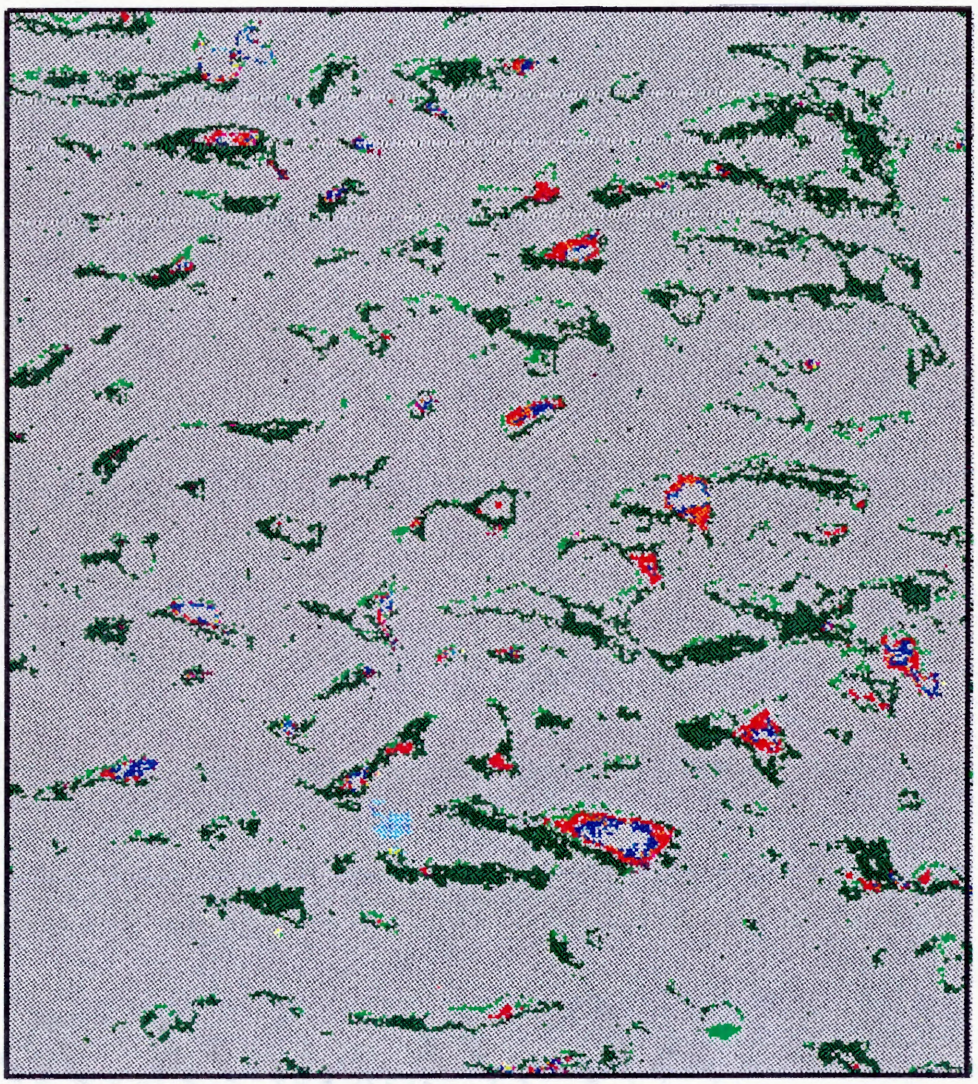
Scale
1 : 233440.43

Legend

- Upland to Water
- Upland to Marsh
- Meadow to Water
- Upland to Meadow
- Meadow to Marsh
- Marsh to Water
- No change
- Water to Marsh
- Marsh to Meadow
- Meadow to Upland
- Water to Meadow
- Marsh to Upland
- Water to Upland

N

Plate 15. Change in Land Cover Classification from 1977 to 1978



Scale
1 : 233440.43

Legend

- Upland to Water
- Upland to Marsh
- Meadow to Water
- Upland to Meadow
- Meadow to Marsh
- Marsh to Water
- No change
- Water to Marsh
- Marsh to Meadow
- Meadow to Upland
- Water to Meadow
- Marsh to Upland
- Water to Upland

N

Plate 16. Change in Land Cover Classification from 1978 to 1984

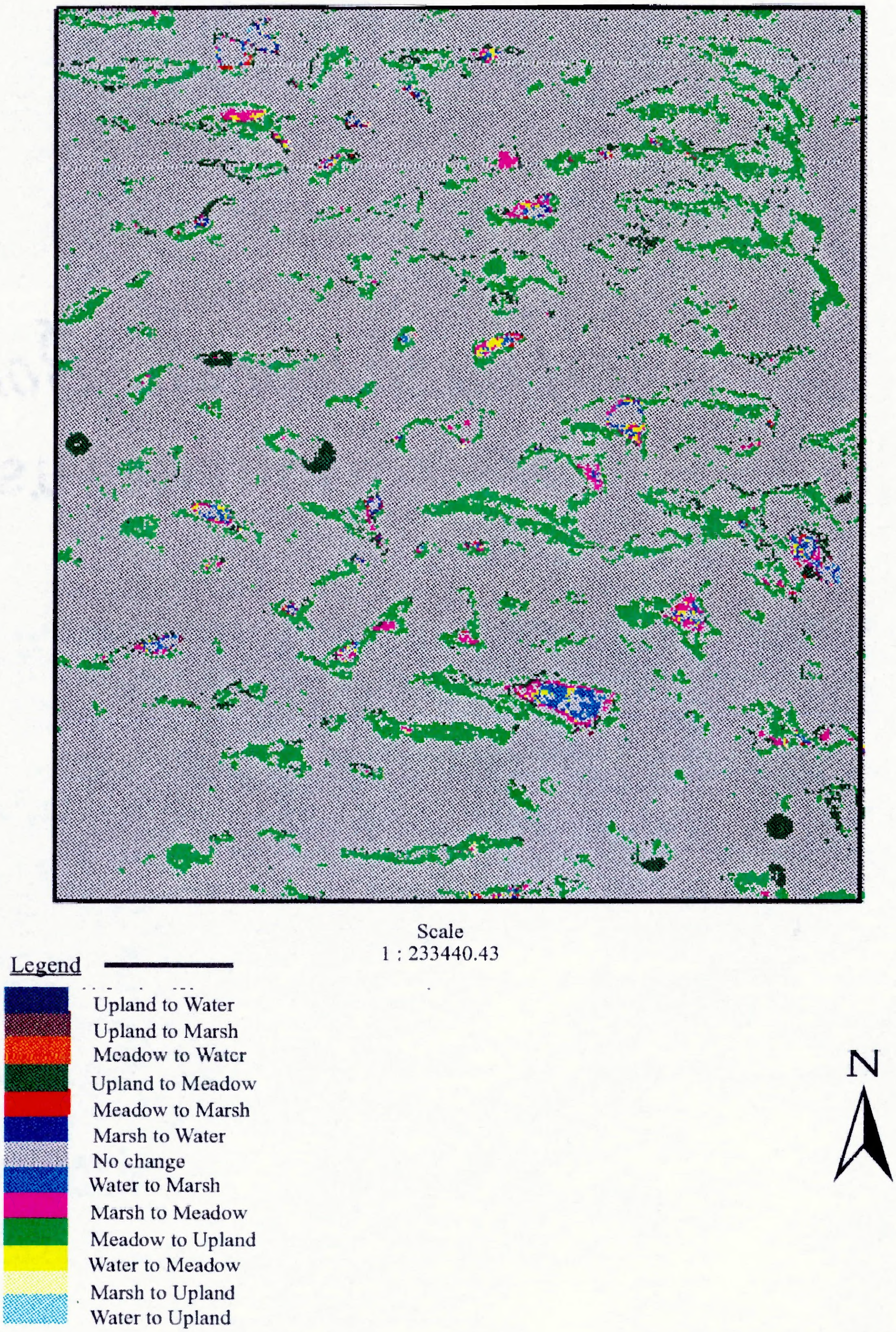


Plate 17. Change in Land Cover Classification from 1984 to 1991

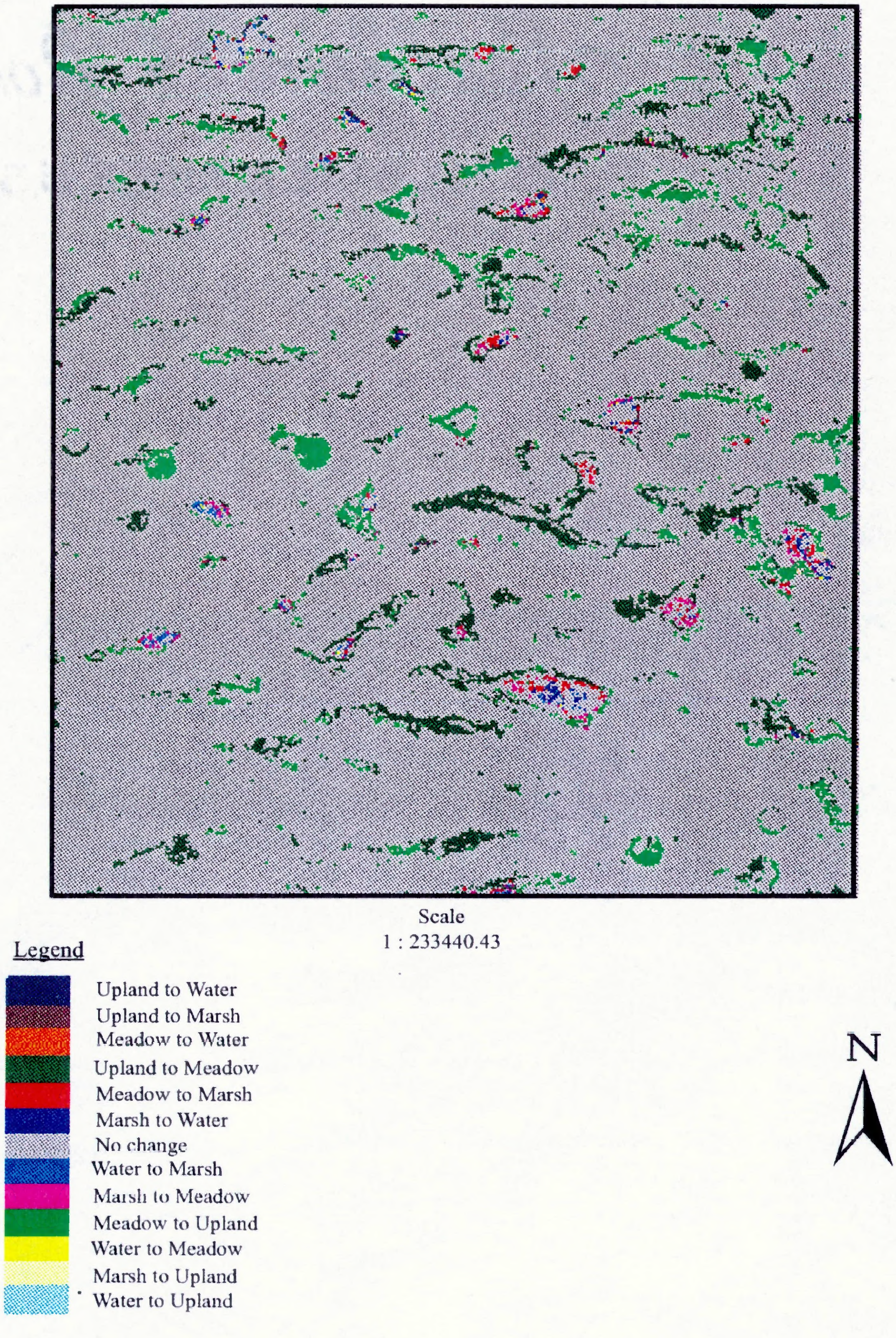
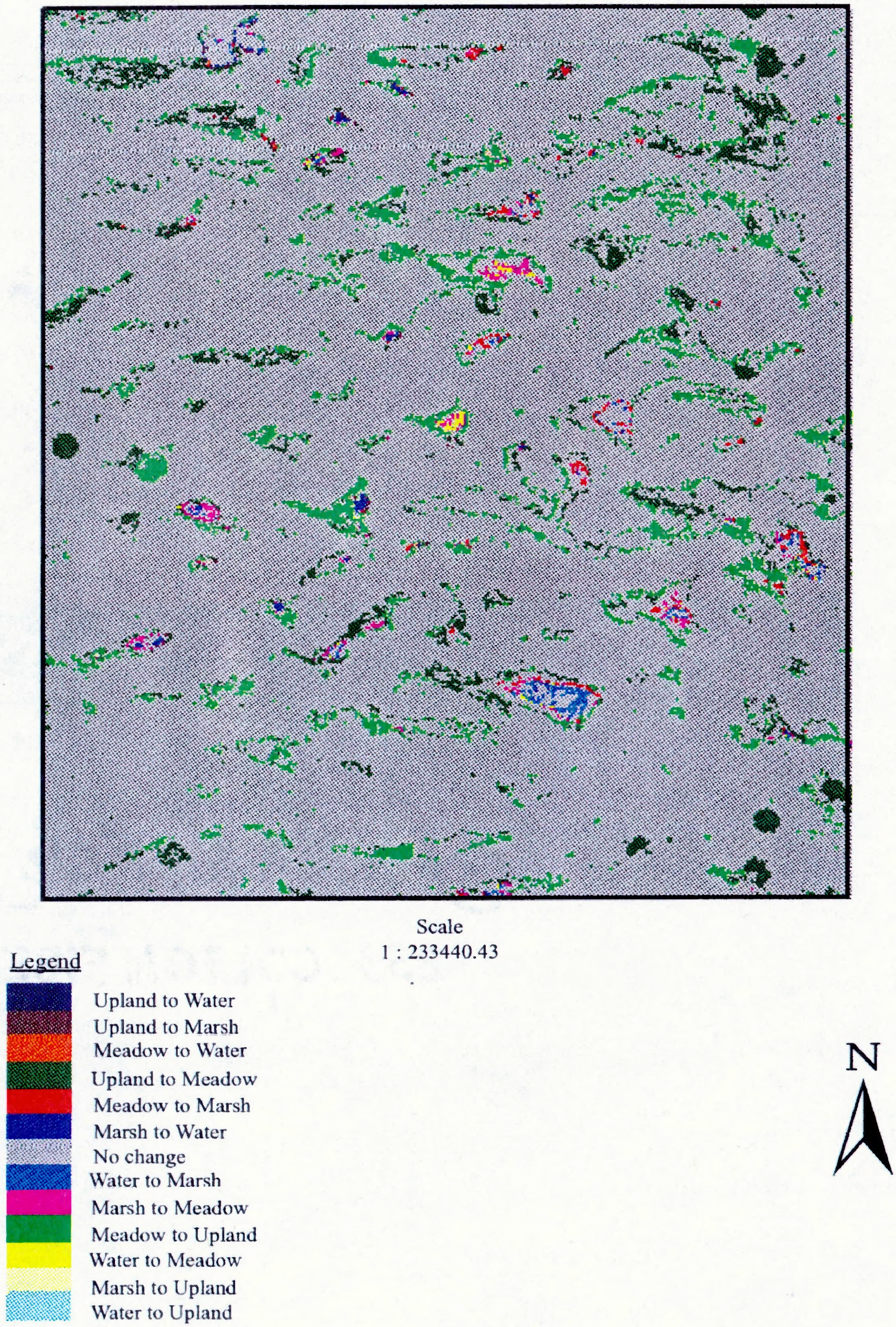


Plate 18. Change in Land Cover Classification from 1973 to 1991



The classification change results for 1973 to 1976 show that the outer edges of meadows in 1973 were classed as upland in 1976. However, there were more meadow to upland changes from 1973 to 1976 and these were located between the edge and the middle of the 1976 meadow areas. The interior of most meadows remained the same. There were scattered areas that changed from marsh in 1973 to meadow in 1976, but especially around Snyder, Cheyenne, and Threemile and about the same amount of hectares changed from meadow to marsh, mostly around Box, Vinton, and Swan, and some small wetlands. Box Lake and the edges of Threemile Lake showed large changes from water to marsh while such changes were sparse elsewhere. On the other hand, Sand Puddin' and Bean Soup Lake experienced changes from marsh to water. Other changes were scattered and/or sparse, although there were clusters of water to meadow and marsh to upland changes. Generally, the greatest absolute change occurred at the meadow/upland interface, although some of the highest relative change occurred in the water and marsh classes.

Compared to 1977, most meadow areas were much larger throughout the 1976 image, mostly involving outer edges, but also including some interior areas. There were, however, some upland to meadow changes in the northeast and around Brown Lake and in a 1977 center pivot area in the southeast. Several marshes in 1976 and Box, Swan, and Threemile Lake had areas classified as meadow in 1977. Meadow to marsh changes were very scattered, but a relatively large area to the south of Spring Valley Lake and also around Brown Lake underwent this change. Most of the marsh to water change was seen in Threemile and surrounding wetlands, except for a few in the northwest while water to marsh changes were less clustered and seen in Threemile Lake and Box Lake. Higher magnitude fluctuations were seen in the marsh to upland change in Spring Valley Lake and Vinton Valley and the upland to marsh changes in and around Spring Valley. The large upland to water change that is depicted in Plate 14 is due to a cloud shadow and therefore does not represent environmental change.

The land cover change between 1977 and 1978 is relatively large. There were many areas, edges as well as many "interiors," that were classified as upland in 1977, but were meadow in 1978. There were also several areas that went from meadow to marsh, some involving almost entire meadows, especially at Threemile Lake and in the upper center of the study area. Many small wetlands and the edges of most lakes—especially Threemile, Claw, and K.C.—had changes from marsh to water. Most of the changes involved a change from a drier category in 1977 to a wetter category in 1978. There were also more areas that experienced larger changes in classification, such as in Spring Valley and the marsh to the south of Spring Valley Lake. The large water to upland change area in the south is due to a cloud shadow in 1977.

The class change image for 1978 and 1984 shows that the meadows were more vigorous in 1978, and even some interior areas in 1978 changed to upland. But, center pivot irrigation caused some upland areas in 1978 to be classed as meadow in 1984. Other upland to subirrigated meadow changes were few and scattered. Variations in the nature of the different wetlands in the study area caused some wetlands to change from meadow to marsh, although a greater number of other areas changed from marsh to meadow. Most wetlands experienced water to marsh changes. There were several patches of water to meadow changes around lakes and small wetlands. There were more marsh to upland changes, mostly in and around Threemile and Spring Lake, than upland to marsh changes.

There were many areas that were upland in 1984, but were classed as meadow in 1991. There was, however, meadow to upland change in 1984 center pivot irrigation areas and the edge of some meadows. There was about an equal amount of change from marsh to meadow as there was from meadow to marsh. Much of these marsh/meadow changes occurred within different parts of the same wetland areas. The edges of small marshes, Threemile Lake, and Brown Lake had several pixels that changed from marsh to water, while parts of Sand Puddin' Lake, K.C. Lake, and the edges of Spring Valley and some small marshes had changes from water to marsh. Other changes were scattered and sparse, except, perhaps, the upland to marsh changes around Spring Valley.

The change in land cover over the study period, as illustrated in the change image for 1973 and 1991, was variable for meadows. The edges of some meadows in 1973 were classed as upland in 1991, with larger areas around Brown Lake, west of Baldy Valley, and in Snyder Valley. But, there were also many areas that changed from upland to meadow, including areas that had center pivot irrigation in 1991, the Threemile Lake area, and in the northeast and northwest. Neither change dominated, with 5662 pixels showing meadow to upland change and 4871 pixels showing upland to meadow change. Likewise, there was variability in marsh/meadow changes. Portions of Snyder Valley, Box Lake, Sand Puddin', the south edge of Threemile Lake, and some valleys had changes from marsh to meadow. Meanwhile, parts of Brown Lake, the northern edge of Threemile, the wetland to the south of Spring Valley Lake, and several scattered wetlands fluctuated from meadow to marsh. Water to marsh changes were seen around the edges of Threemile Lake, Swan, and Brown Lake, and in several scattered wetland areas. A marsh to water change occurred in parts of Sand Puddin' Lake, Spring Valley Lake, the wetland to the west of Baldy Valley, and some small wetlands. There was a relatively large area of marsh to upland change in Vinton Valley, while other wetlands, especially in the northwest, had small areas of upland to marsh changes. Cheyenne Lake and Snyder Valley had several pixels change from water to meadow.

To summarize the land cover changes, the meadows experienced the greatest absolute change over time: large areas changed from being classed as meadow one year to being classed as upland another year. The greatest relative change is seen in the marsh category, which is confirmed by the persistence statistics. The greatest magnitude of change - involving changes across two or more classes; e.g., marsh to upland - occurred in small wetland areas associated with water and marsh land covers. There was a lot of spatial variation in the land cover changes. Some wetlands for a particular image date comparison changed from a drier to wetter category while other wetlands went from a wetter to drier category. For example, Sand Puddin' Lake and K.C. Lake often had opposite change than the change that occurred in Threemile Lake. There was also variation of change within the same wetland.

3. *Spectral Versus Land Cover Changes*

There appears to be a strong relationship between the spectral changes of wetlands, as revealed in the residual images, and the land cover classification changes. Thus, the second hypothesis, which states that statistically significant spectral changes are related to land cover class changes, is accepted. Negative residuals, highlighting lower TVI and NIR values for the later year of each yearly comparison, are usually associated with a land cover change to a wetland class that has lower spectral response properties. For example, the negative residuals and class change images for 1976 and 1977 show that there were fewer meadow areas in 1977 and less water and more marsh in Threemile than in 1977. Also, the wetland to the south of Spring Valley Lake was marsh in 1977 and meadow in 1976, which relates to lower spectral values in 1977. Positive residuals also tend to relate to land cover changes. For instance, the classification change image for 1977 and 1978 shows that many areas that were classed as upland in 1977 were meadow in 1978, while the positive residuals image shows the TVI and near-infrared values were higher in 1978 than in 1977, which coincides with a change from upland to meadow. The near-infrared residuals image did a better job of highlighting very high residuals spectral values in wetlands that relate to upland to marsh and meadow to water land cover changes in the classification images.

However, there were also some changes in the residuals and land cover change images that did not coincide with each other. The near infrared residuals images were more sensitive to the make up of the water surface. The change in aquatic plants, turbidity, and lake depth has a significant effect upon the near-infrared response of the lake surface. This is also true to a lesser extent for TVI values. This does not mean that the water class should have changed to marsh for these areas. Indeed the land surface is still probably water, only the water is less pure and probably consists of sediment, submergents, and other aquatic plants. The best example of this is seen in the negative residuals images for 1978 and 1984. The 1978 image was from early in the growing season when aquatic plants would not be fully established and the 1984 image is from late in the season when they are mature and covering the greatest surface area. Even dying vegetation covering the surface would have higher TVI and NIR values than clear water. Thus, the lakes show higher values for 1978 than for 1984. But the surface is still water, therefore the land cover should not be classed as marsh but should remain as water. The residual images, showing moderate to very high or very low change in the spectral characteristics of water, but without a coincident change in land cover, still provide beneficial information on the changing nature of lake water characteristics. The changes in meadows had the highest relationship between residual and class change images.

Chapter VIII

DISCUSSION

Although statistical analysis revealed that there was not significant change in the land cover between each image date, there was still change occurring in the spectral response of the land surface which resulted in land cover classification changes. Change image analysis illustrated where and what types of changes were occurring, which helps in understanding the processes at work in the region. Although not a part of the emphasis of this study, several possible rationales are offered for the land cover changes.

The change in land cover and the spectral response seen in the data may have been caused by the soil moisture conditions, the stage of plant growth, hay-harvesting operations, or even by the preprocessing and georegistration procedures. The soil moisture varies depending mostly upon rainfall and evapotranspiration fluctuations, which impacts groundwater levels. The length of time between a rainfall event and a satellite overpass will cause the soil moisture to appear wetter or drier than yearly or seasonal conditions would otherwise indicate. Higher groundwater levels may allow for meadows to expand into upland areas and may enable the establishment and/or proliferation of hydric plant species in previously drier land cover areas. This would indicate longer term change since this process could take at least a few years.

Other land cover changes may be due to different stages of plant growth. The spectral response of plants changes over the growing season, with the most biomass, and thus the greatest reflectance in the near-infrared, between early growth and maturity of the plant. Late in the season plants undergo senescence and the soil moisture conditions are lower, resulting in a reduction in area and biomass of a plant group. This may be the case for the image comparison of 1978 with 1984, with the former being early in the growing season and the latter being late in the season. Wetland area decreased while upland increased.

Hay-harvesting may also cause changes in the spectral response and the classification assigned to the land cover. The mowing of hay is commonly conducted later in the growing season. Thus, the relatively small amount of meadow hectares in August 1977 and August 1984 may be caused mostly by the harvesting of hay. The spatial variations of change in meadow/upland may be due to different mowing practices such as timing and extent. Of course, some of this change is due to the reduced plant vigor later in the growing season, which also varies spatially, depending upon soil moisture conditions, which in turn are related to the depth to the water table.

Finally, some of the change in land cover and/or spectral response of the wetlands may have been caused by the preprocessing or classification procedures. There is always the possibility that the radiometric preprocessing corrections, though theoretically based and accepted within the discipline, were not able to convert the digital number values to accurate reflectance values for each pixel. However, the characteristics of each sensor for each image date and the atmospheric conditions were taken into account, thereby limiting this variable's effect on the results.

The georegistration procedures also cannot assure that pixels for different dates represent the same precise land surface area. But, by obtaining an RMS error of less than .5 for each image, overlays can be performed so that the land surface location does not vary significantly between images. The classification procedure may have assigned some pixels to the wrong land cover category, so that a change would be predicted when in reality no change occurred, or conversely, so that no change would be depicted when in actuality a change had indeed occurred. But, by using the same classification methodology for each image date, using statistical and visual analysis to define wetland clusters and classes, the pixel assignment to a particular land cover would be consistent and logically valid.

The change images illustrated the spatial variations of wetland change. For example, some lakes experienced change from water to marsh or marsh to water more than other lakes. The lakes in the study area are shallow, averaging less than two meters (Bleed and Flowerday, 1990). Shallow lakes allow for emergents and other aquatic plants to grow more abundantly, which results in increased near-infrared reflectance. Other factors such as ground water flow, turbidity, and lake chemistry also impact the growth of aquatic plants, with the latter two having a direct effect on the spectral response of the lakes. Such lakes as Threemile, Sand Puddin', K.C., and Brown have properties that result in a great deal of fluctuation in the land cover classification and spectral response both annually and seasonally. This illustrates that there are definite spatial variations in the types of changes occurring, and that some of the change is local in nature. As a further example, simultaneous with meadow to marsh changes, other wetlands, or even different parts of the same wetland, changed from marsh to meadow. The size of the wetland and the degree of soil moisture/depth to water table seem to influence these changes.

In multitemporal studies, the main objective is to analyze either seasonal or yearly changes in the land cover. However, in this study, due to the 18-day temporal resolution of Landsat MSS making it difficult to obtain anniversary date images of high quality, both seasonal and yearly influences are probably effecting the spectral and land cover class changes. Seasonal variation is important to examine since it gives an indication of plant growth, lake surface fluctuations, and soil moisture changes. But, a seasonal evaluation requires several images over the course of a single growing season. Dealing with six images covering nineteen years for different dates of the season makes it difficult to assess whether the changes are due to fluctuation that may indicate long-term processes occurring, or if the seasonal changes have more influence in the changes between different years. The ideal would be to have 20 images for the same point in the stage of a plant's growth covering each year in the study period. But since this is not possible, it is necessary to try to determine which variations are due to seasonal changes and which are due to yearly fluctuations due to plant growth. The year pairs with the greatest seasonal difference—08/01/77 versus 06/12/78 and 06/12/78 versus 08/11/84—have the lowest Kappa values and the highest percent hectare change for all classes. In addition, the

1977/1978 comparison is for only one year difference and the residuals and class change images for these years show that a relatively high percentage of the land covers changed. In contrast, the comparison over the entire study period—1973 versus 1991—had a higher Kappa agreement value than the images with the highest seasonal difference. The relatively close dates (12 days difference) between the 1973 and 1991 images indicate seasonal differences are larger than yearly differences, which is to be expected. However, except for the images that seemed to have most of their change due to seasonal change, the 1973 to 1991 comparison had the lowest Kappa value. And its water persistence was the second lowest of all comparisons. But, from this it cannot be concluded that any long-term changes have occurred or that any patterns are evident. Variation may be due to yearly rainfall fluctuations, differences in range management practices, or other short-term influences.

Chapter IX

CONCLUSIONS AND RECOMMENDATIONS

This study developed a method for examining change in a small region through the use of a dual-approach to change detection that encompassed both spectral and land cover classification change. The classification methodology provided a consistent and reliable procedure that can be used for future studies. By using a hybrid method, the classification results take advantage of both unsupervised and supervised classification methods and help to limit the disadvantages of each.

Statistical analysis revealed that there was no significant change in the land cover during the study period. There was, however, a moderately high amount of unexplained variation in the spectral response of the land surface and many areas experienced land cover changes, with some of the latter changes being across two or more categories. The changes were both temporal and spatial in nature.

This study found that apparent seasonal differences were greater than changes observed during the course of the study period. Variations in the vegetative stage of plant growth caused the spectral response and land cover class changes to be relatively high. No long term processes or patterns were discovered to be affecting the wetlands of the study area.

In order to more fully understand the patterns and processes of change in the wetlands, it is recommended that future research be conducted. This study's data base will have to be maintained and updated. New imagery acquisition will have to include both past imagery data and future satellite overpasses. New imagery should involve closer image dates. These dates should preferably be obtained during the mid-growing season - from late June to mid-July - in order to portray the wetland better and avoid mowing-caused changes to meadows late in the season and the lack of marsh growth earlier in the season. Landsat Thematic Mapper (TM) data may have to be used for imagery obtained after 1993 since the MSS sensor has been shut off. The integration of TM and MSS data has been done previously with acceptable results (Dinville, 1993; Larsson, 1993) and involves the degrading of the spatial resolution of the TM data to the MSS spatial resolution. Using only TM data would cause the loss of about ten years of data. The closer date imagery for future studies would assist in limiting changes to yearly fluctuations. Seasonal change analysis of the region can be done using such high temporal resolution sensors as SPOT.

The classification procedure and subsequent data analysis would be aided by the collection of field data at the time of a satellite overpass. Current reference maps are few and inconsistent with conventional classification procedures and spectral analysis methods. Other data such as hydrologic data should be integrated with the imagery data in a geographic information system (GIS).

In order to determine if there are regional variations of wetland change in the Nebraska Sandhills, the results and/or data from this study may be integrated with the data of other wetland studies in the Sandhills. Direct comparisons between regions could be done if the methodology was the same for each region. This would further assist in understanding the processes that are causing local changes and may lend insight into regional differences. By combining the remote sensing data with other data such as the geology, biology, climatology, geomorphology, hydrology, and range management practices of each region, variations of regional change may be explained by the differing nature of the areas.

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APPENDIX A

Landsat MSS Imagery Information

Date Acquired	Identification Number	Cloud Cover	Path/Row	Sun Elevation
07/26/73	LM8136817014500	1	34/31	57
07/01/76	LM8252616433500	1	34/31	57
08/01/77	LM8292216272500	1	34/31	50
06/12/78	LM83009916500X0	0	34/31	59
08/11/84	LM85016316541X0	0	31/31	53
07/14/91	LM85269116474X0	0	31/31	57

APPENDIX B

Gain, Offset, and Gain Normalization Factors for Landsat MSS

Application Date: July 26, 1973

Band	Gain	Offset	Normalization*
1	24.8	0.0	1.00
2	20.0	0.0	0.81
3	17.6	0.0	0.71
4	15.3	0.0	0.62

Application Dates: July 1, 1976 and August 1, 1977

Band	Gain	Offset	Normalization
1	26.3	0.8	1.00
2	17.6	0.6	0.67
3	15.2	0.6	0.58
4	13.0	0.4	0.47

Application Date: June 12, 1978

Band	Gain	Offset	Normalization
1	25.9	0.4	1.00
2	17.9	0.3	0.69
3	14.9	0.3	0.58
4	12.8	0.1	0.49

Application Date: August 11, 1884

Band	Gain	Offset	Normalization
1	26.8	0.3	1.00
2	17.9	0.3	0.67
3	15.9	0.4	0.59
4	12.3	0.3	0.46

Application Date: July 14, 1991

Band	Gain	Offset	Normalization
1	26.8	0.3	1.00
2	17.9	0.3	0.67
3	14.8	0.5	0.55
4	12.3	0.3	0.46

---

*Normalization factors are computed by dividing the starting haze MSS band (1) gain value into the gain values of the other given bands. Thus, normalization for Landsat-1 band 2 was found by dividing 20 by 24.8. Gain and offset values from Clark (1986, p. 4) specified as LMIN and LMAX.

APPENDIX C

Starting Haze Values and Associated Predicted Haze Values

Year	SHV	DN(OUT) Band 2	DN(OUT) Band 3	DN(OUT) Band 4*
1973	16	6.64848	3.28304	.551145827
1976	11	4.38081	2.44382	.497888504
1977	6	2.86226	1.60572	.361768819
1978	9	3.48573	1.80858	.294621732
1984	8	3.04968	1.76408	.71216
1991	8	3.04968	1.7716	.71216

*Band 4 DN(OUT) values are standardized to other band values by multiplying by a ratio of 63 to 127 for image dates 1973 to 1978.

APPENDIX D

Radiance Haze Values at 1% Reflectance*

Year	Band 1	Band 2	Band 3	Band 4
1973	3.093165354	1.036534677	.450422748	.132511204
1976	2.978574803	1.174543562	.872133656	.494581924
1977	1.984677165	0.973305798	.776748637	.467630226
1978	2.185015748	0.775231177	.502836341	.157798080
1984	1.949598425	0.715406491	.609148091	.363617802
1991	1.949598425	0.715406491	.692484576	.363617802

*Using DN(OUT) value inserted into Equation #1 and then multiplying by .99.

APPENDIX E

Multiplication Factors (HAZE) to Predict Haze Values

	Atmospheric Condition	
Band	Very Clear λ^{-4}	Clear λ^{-2}
1	1.000	1.000
2	0.513	0.716
3	0.289	0.538
4	0.112	0.335

(Source: Chavez, 1988)

APPENDIX F

MSS Mean Solar Exoatmospheric Spectral Irradiances (ESUN)

Satellite	Band 1	Band 2	Band 3	Band 4
Landsat-1	185.2	158.4	127.6	90.4
Landsat-2	185.6	155.9	126.9	90.6
Landsat-3	186.0	157.1	128.9	91.0
Landsat-5	184.9	159.5	125.3	87.0

(Source: Clark, 1986)

APPENDIX G

Procedure for Exporting Data

A. *Spectral Data*

After all the images had been classified and spectrally enhanced, data analysis needed to be performed. It was determined that IMAGINE did not have the data analysis capabilities necessary to perform the operations desired. A regression analysis was to be conducted on the spectral data, for both TVI and near-infrared values, using the SPSS statistical software package (SPSS, 1990) on the VAX operating system. The spectral data were computed in floating point format in order to obtain the highest degree of accuracy as possible, preventing truncation of values. The data had to imported into the VAX in text format due to differences between IMAGINE's floating point format and the format SPSS recognizes. Each pixel value was converted into 16-bit format data after multiplying by a scalar (10,000 for TVI and 1000 for near-infrared) to limit the truncation. This created accuracy to four decimal points for the TVI data and three decimal points for the near-infrared data. Analysis of the original values showed that this maintained the separability of the individual spectral values.

Satellite images contain header files which have ancillary data about the image. This data needs to be "stripped" so that it is not included in the analysis program. IMAGINE does not allow for export of 16-bit data as generic binary data. The header files were stripped with the UNIX command:

```
dd if=input image of=output data file ibs=1 obs=512 skip=128        (Eq. G1)
```

where

dd	= Convert and copy files
if	= Input file
of	= Output file
ibs	= Input block size n bytes
obs	= Output block size n bytes
skip	= Skip n input records before starting copy

The 16-bit data values needed to be converted to integer values for ease of use in SPSS and for viewing of data value files prior to export. This assisted in assuring that accurate spectral values would be analyzed. The 16-bit values are stored in IMAGINE in reverse order. That is, the 16-bit values are made up of two 8-bit hexadecimal values with the least significant byte stored first. For example, 7b33 represents 13,179 in IMAGINE'S hexadecimal format, although if it was to be read sequentially, the number would be seen as 31,539. Thus, the two 8-bit values needed to be swapped.

The standard format used to distinguish variables in SPSS is to have the main variables be represented in a separate set of columns. For example, columns 1-3 may represent variable number one, columns 5-7 may represent variable number 2, and so forth. Further variable subdivisions are then possible by specifying a value or range of values from the original variable data. Each satellite image contained numerous columns and rows of data values that needed to be ordered into one column group. A Perl programming script was applied to each image's data to swap the bytes of the hexadecimal values, then convert the hexadecimal format to text format, and then arrange the values into a single column group. Figure G1 shows the Perl program, named hex2int.

Figure G1. Perl Program for Converting Hexadecimal Data to Text Format

```
#hex2int
#!/usr/bin/perl

# Use the file they specified, if specified

#die "
#  Usage: hex2int [file]
#  swaps the bytes of 16 bit data  F3333 should be 33F3

#die "
#  Usage: hex2int (file)  > (new_ascii_output.file)
#   ## the > redirects the output of hex2int into the new output file\n"
#        if ( $ARGV[0]  == '' );


# Use the file they specified, if specified
open(STDIN,$ARGV[0]) || die "Can't open dataset file $ARGV[0]: $!\n"
    if $ARGV[0];
#

while (($len = read(STDIN,$data,2)) == 2) {
   ($array[1], $array[0]) = unpack('C2', $data);
   $thepixel = pack('C2', @array);
   printf "%5.5d \n", unpack('n', $thepixel);
#
#just to debug
#   printf "%7.7d %7.7d %7.7d \n", $array[1], $array[0], unpack('n', $thepixel);
}
```

Individual data files were then combined into files containing two or three separate imagery data files. (All the imagery data could not be combined into one file due to computer memory limitations on the VAX computer system). The combined files contained tab characters that separated the column group data values and these needed to be changed into a space character in order to be recognized by SPSS. A stream editor command was used to replace the tabs with a space, as follows:

```
sed -e 's/ <control v tab>/ /g' -e 's/\ $//' infile >outfile        (Eq . G2)
```

where

sed	= Stream editor
-e	= Edit command
s	= Substitute
control v tab	= Insert tab character
g	= Global
$	= Addresses the last input line

The data files were then ftped (file transfer program) to the VAX system for use in SPSS.

B. *Classification Data*

The classification data were also analyzed in SPSS. The original rectified classification files were in 8-bit binary format which could be exported in Imagine as generic binary files, which stripped the header and trailer files from the imagery data files. The generic binary data were then converted to text format, to aid in viewing the values before export and thus to assure accuracy. This was done using a Perl programming script which converted the binary data into text format and arranged the data into a single column group. This program is seen in Figure G2 and is named byte2int. As with the spectral data, the files were pasted together into combined files and then the tabs were replaced with spaces with equation G2. These files were then ftped to the VAX system for analysis.

Figure G2. Perl Program for Converting Binary Data to Text Format

```
#byte2int
#!/usr/bin/perl

# Use the file they specified, if specified

#die "
#  Usage: byte2int [file]
#  single digit output, written as an output field of 2 characters

#die "
#  Usage: byte2int (file) > (new_ascii_output.file)
#   ## the > redirects the output of byte2int into the new output file\n"
#        if ( $ARGV[0]  == '' );


# Use the file they specified, if specified
open(STDIN,$ARGV[0]) || die "Can't open dataset file $ARGV[0]: $!\n"
    if $ARGV[0];
#

while (($len = read(STDIN,$data,1)) == 1) {
        if ($data > 9) {
        print "the data file has a value greater than nine\n";
        } else {
#         printf ("%2.2d\n", unpack( 'C', $data ) );
         printf ("%s \n", unpack( 'C', $data ) );
         };
#
#just to debug
#  printf "%7.7d %7.7d %7.7d \n", $array[1], $array[0], unpack('n', $thepixel);
}
```

APPENDIX H

Accuracy Assessment Program

```
#kappa.c
#include <stdio.h>
#include <math.h>

/*    Classification error matrix and Kappa Coefficient */

/*    SYNTAX: Kappa <training.dat> <classification.dat> {standard output} */
#define NLINES        390        /* number of lines           */
#define NCOLUMNS       338        /* number of columns          */
#define NCLASSES      4         /* number of classes          */
#define NTRAINING      161        /* number of training samples  */


typedef struct statistical_data {
      int   pixelx;
      int   pixely;
      int   class;
      int   reference;
} Data;

typedef struct training_data {
      int   x1;
      int   y1;
      int   x2;
      int   y2;
      int   reference;
} Training;


FILE *f1, *f2;
Data *data;
Training training [NTRAINING];
int matrix_count [NCLASSES] [NCLASSES], N;
float matrix_percentage [NCLASSES] [NCLASSES];


int main ( argc, argv)
int argc;
char *argv[];
{
      void read_ascii_file (), create_statistical_data_file (), calculate_erro
r_matrix (),
```

```
        print_error_matrix (), calculate_kappa_statistics ();

        (void) read_ascii_file ( argv );

        data = (Data *) malloc ( sizeof (Data) * N );

        (void) create_statistical_data_file ( argv );

        (void) calculate_error_matrix ();

        (void) print_error_matrix ();

        (void) calculate_kappa_statistics ();

        return 0;
}
/*
unsigned char **array2d ( row, col )
int row, col;
{
        char *calloc ();
        int i;
        register unsigned char **prow, *pdata;

        pdata = (unsigned char *) calloc ( row*col, sizeof (unsigned char));
        prow = (unsigned char **) calloc ( row, sizeof (unsigned char *));
        for ( i = 0; i < row; ++i ) {
                prow [i] = pdata;
                pdata += col;
        }
        return prow;
}
*/
void read_ascii_file ( argv )
char *argv[];
{
        register Training *p = training;
        register Training *end = training + NTRAINING;
        char buffer1 [50], buffer2 [50];
        char buffer3 [50], buffer4 [50], buffer5 [50];
        void exit ();

        f1 = fopen ( argv[1], "r" );
        N = 0;
        for ( ; p < end; ++p ) {
                (void) fscanf ( f1, "%s%s%s%s%s\n", buffer1,buffer2,buffer3,buff
er4,buffer5 );
                p->x1 = atoi ( buffer1 );
                p->y1 = atoi ( buffer2 );
```

```
        p->x2 = atoi ( buffer3 );
        p->y2 = atoi ( buffer4 );
        p->reference = atoi ( buffer5 );
        N += ((p->x2 - p->x1 + 1) * (p->y2 - p->y1 + 1));
    }
    (void) fclose ( f1 );
}


void create_statistical_data_file ( argv )
char *argv[];
{
    register int i;
    register int j;
    register Data *s = data;
    register Training *p = training;
    register Training *end = training + NTRAINING;
    unsigned char classification [NLINES] [NCOLUMNS];


    f2 = fopen ( argv[2], "r" );

    (void) fread ((char *) classification, (NLINES*NCOLUMNS), sizeof (char),
f2 );

    (void) fclose (f2 );

    (void) printf ("read data N = %d\n", N );

    for ( ; p < end; ++p ) {
        for ( i = p->y1; i <= p->y2; ++i )
            for ( j = p->x1; j <= p->x2; ++j ) {
                s->pixelx = j;
                s->pixely = i;
                s->class = classification [i] [j];
                s->reference = p->reference;
                ++s;
            }
    }
}

void calculate_error_matrix ()
{
    register int i;
    register int j;
    register Data *s = data;
    register Data *end = data + N;

    for ( i = 0; i < NCLASSES; ++i )
```

```
		for ( j = 0; j < NCLASSES; ++j )
			matrix_count [i] [j] = 0;

	for ( ; s < end; ++s )
		matrix_count [s->reference-1] [s->class-1] += 1;


	for ( i = 0; i < NCLASSES; ++i )
		for ( j = 0; j < NCLASSES; ++j )
			matrix_percentage [i] [j] = (float) matrix_count [i] [j]
/ (float) N;
}

void print_error_matrix ()
{
	register int i;
	register int j;

	for ( i = 0; i < NCLASSES; ++i ) {
		for ( j = 0; j < NCLASSES; ++j )
			(void) printf ( " %.8d", matrix_count [i] [j] );
		(void) printf ( "\n" );
	}
	for ( i = 0; i < NCLASSES; ++i ) {
		for ( j = 0; j < NCLASSES; ++j )
			(void) printf ( " %6.5f", matrix_percentage [i] [j] );
		(void) printf ( "\n" );
	}
}

void calculate_kappa_statistics ()
{
	register int i;
	register int j;
	float class_kappa [NCLASSES];
	float kappa = 0.0, po = 0.0, pc = 0.0, sum1, sum2;

	for ( i = 0; i < NCLASSES; ++i )
		po += matrix_percentage [i] [i];

	for ( i = 0; i < NCLASSES; ++i ) {
		sum1 = 0.0;
		sum2 = 0.0;
		for ( j = 0; j < NCLASSES; ++j ) {
			sum1 += matrix_percentage [i] [j];
			sum2 += matrix_percentage [j] [i];
		}
		pc += (sum1 * sum2);
		class_kappa [i] = (matrix_percentage[i][i]-(sum1*sum2)) / (sum1
```

```
- (sum1*sum2));
      }

      kappa = (po - pc) / (1.0 - pc);

      for ( i = 0; i < NCLASSES; ++i )
            (void) printf ( "Kappa Coefficient class %.2d ==> %6.5f\n", i+1,
 class_kappa[i]);


      (void) printf ( "Classification accuracy == Kappa Coefficient ==> %6.5f\
n", kappa );
}
```